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PIVIB: A COMPUTER PROGRAM FOR ANALYSIS OF PILOT BIODYNAMIC AND TRACKING RESPONSE TO VIBRATION

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PIVIP (Pilot Response to Vibration) is a digital computer program that predicts both the biodynamic response of a pilot, and the resultant tracking behavior in a single-axis and multiple-axis whole-body vibration environments. The program is written in FORTRAN-IV-EXTENDED computer programming language and is designed for efficient batch operation on a Control Data CDC-6600 computer. The purpose of this report is to acquaint the user with the program and how to operate it.

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PREFACE

The Pilot Response to Vibration (PIVIB) Program was developed by Bolt Beranek and Newman Inc. under contract F33615-76-C-5015 with the Aerospace Medical Research Laboratory. Major C. B. Harrah of the Vibration Branch, Biodynamics and Bionics Division, was the contract monitor for AMRL. The work was performed in support of Project 7231, Task 01, Work Unit 77.

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1. INTRODUCTION

PIVIB (Pilot Response to Vibration) is a digital computer program which provides a quantitative description relating pilot performance to various vibration environments. Specifically, it predicts both the biodynamic response of a pilot, and the resultant tracking behavior in single-axis and multiple-axis whole-body vibration environments.

The PIVIB program is written in the FORTRAN-IV-EXTENDED computer programming language and is designed for efficient batch operation on a Control Data CDC-6600 computer. Data input to the prog4am is provided on standard punched cards, and output is generated via the line printer. The program requires inputs that relate to the vibration environment, biomechanical transfer functions, tracking dynamics, tracking performance requirements, and to the pilot's inherent limitations. The program produces a set of outputs which predict the biodynamic response of the pilot in terms of several vibration spectra and rms vibration measures, and a set of outputs which predict the tracking performance of the pilot in terms of rms tracking scores and pilot describing functions.

The purpose of this document is to acquaint the user with the program and to provide the information needed to operate it. This document consists of sections dealing with the organization of the program, theoretical background, control of the program, input to the program, outputs from the program, program operating instructions, sample problems and solutions, and some details of the program operation.

It is recommended that this manual be read in conjunction with the final report for this contract, "Biomechanical and Performance Response of Man in Six Directional Axis Vibration Environments" (Reference 1).

2. PROGRAM ORGANIZATION

The PIVIB program is organized into three major modules: (1) the Biodynamic Response Module, to predict the response behavior of relevant biomechanical systems, (2) the Pilot/Vehicle Module, based on the optimal-control model, to predict tracking performance, and (3) the Executive Module to facilitate communication between the biodynamic and tracking modules. An overall block diagram of the PIVIB program is given in Figure 1.

Modularity of the overall structure is desired for ease of future model development. This is especially important with regard to biodynamic modeling, which is still in its formative stages. For example, as specialized biodynamic response models become available in the future, it will be possible to restrict program modifications to the relevant subprograms dealing with the specific biodynamic response mechanisms.

The modular design of the program also facilitated the division of the program into overlays. The executive module resides in the main overlay (along with several frequently referenced subroutines), while the other two modules each reside in separate primary overlays. Overlaying the program allows it to run in a considerably smaller field length than it would otherwise need.

2.1 EXEC MODULE - VEXEC

The Exec Module performs virtually no computations. It simply allows the user to enter either the Biodynamic Response

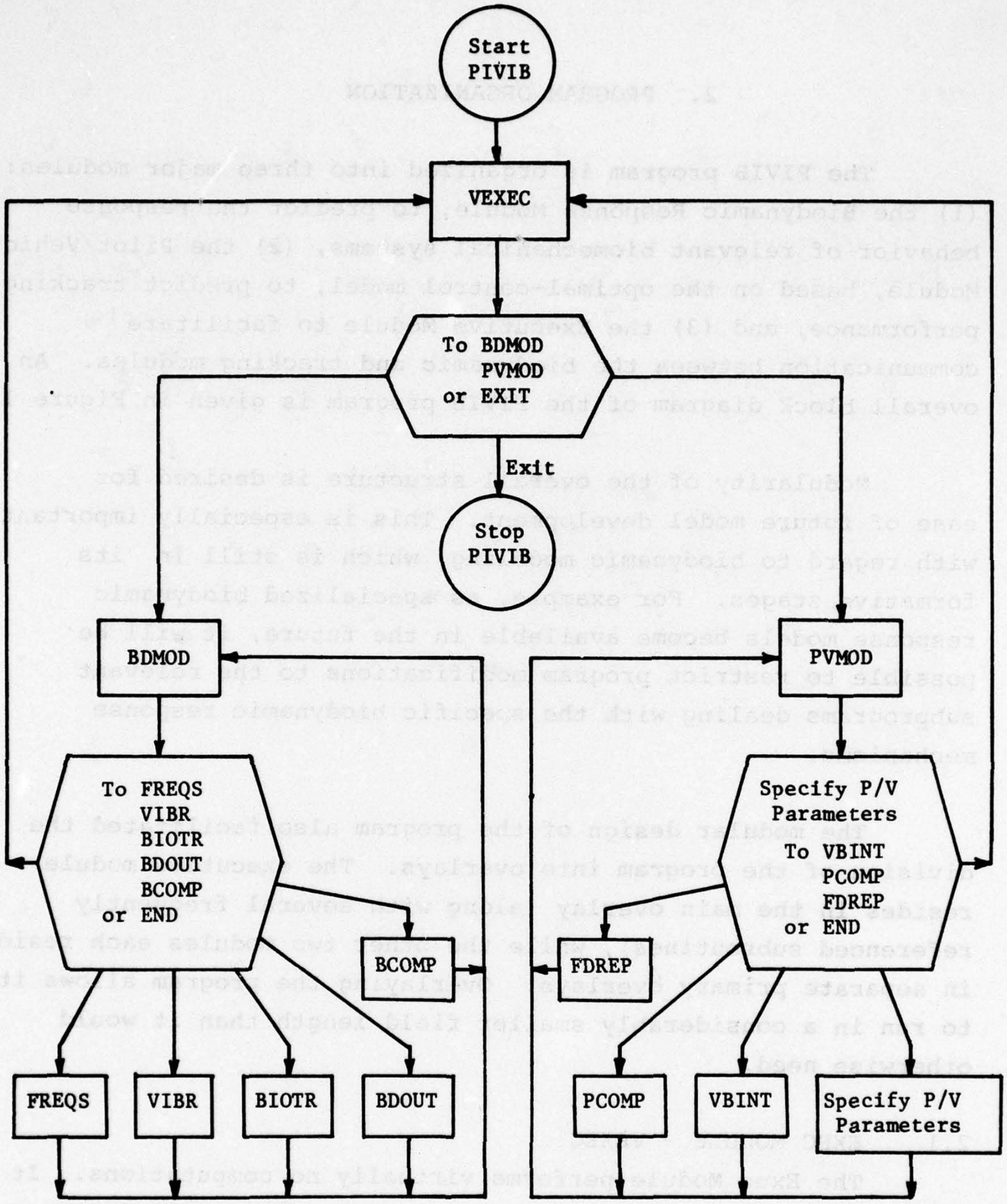

Figure 1. Overall Block Diagram of the PIVIB Program

Module, or the Pilot/Vehicle Module, or to terminate the program operation. In addition, it contains the COMMON blocks through which the other two modules communicate.

2.2 BIODYNAMIC RESPONSE MODULE - BDMOD

The Biodynamic Response Module consists of five submodules which are directly accessed by the user, and various utility submodules. The five accessible submodules are:

1. FREQS - Frequency specification for biodynamic analysis;
2. VIBR - Vibration environment specification;
3. BIOTR - Biodynamic transfer function specification;
4. BDOUT - Biodynamic output specification;
5. BCOMP - Biodynamic computation.

2.3 PILOT/VEHICLE MODULE - PVMOD

The Pilot/Vehicle module consists of three submodules which are directly accessible to the user, as well as various utility submodules. The three user accessible submodules are:

1. PCOMP - Pilot/Vehicle Computation;
2. VBINT - Vibration Interface;
3. FDREP - Frequency Domain Computation.

In addition, the user has the facility to specify the parameters of the pilot/vehicle model, such as the vehicle dynamics, the pilot's observation noise ratios and perceptual time delay, etc.

3. THEORETICAL BACKGROUND

This section gives the theoretical background for the PIVIB program. The BDMOD module is described first, followed by the PVMOD module.

3.1 BIODYNAMIC RESPONSE MODULE - BDMOD

The theory underlying the biodynamic response module is straightforward. The pilot is seated on a vibrating platform. The various parts of his body, in particular his shoulders and head, vibrate in response to this input vibration. The pilot, who is engaged in a tracking task, is holding a control stick in his hand and is observing a display in front of his head. Thus, the control stick and the displayed tracking variables (coupled through the tracking dynamics) also vibrate in response to the vibration input. Furthermore, because the pilot's head is vibrating, his eye-point-of-regard (vis-a-vis the tracking display) also vibrates in response to the vibration input. Figure 2 illustrates the 6 axes of platform/pilot vibration, and 2 axes of stick/display vibration.

It is the job of the BDMOD module to compute each of these biodynamic vibration responses, given the nature of the input platform vibration and the relevant biodynamic transfer functions. Specific transfer functions are not programmed into the model; they are input by the user at runtime.

All vibration and biodynamic variables are specified in the frequency domain, and frequency domain integration

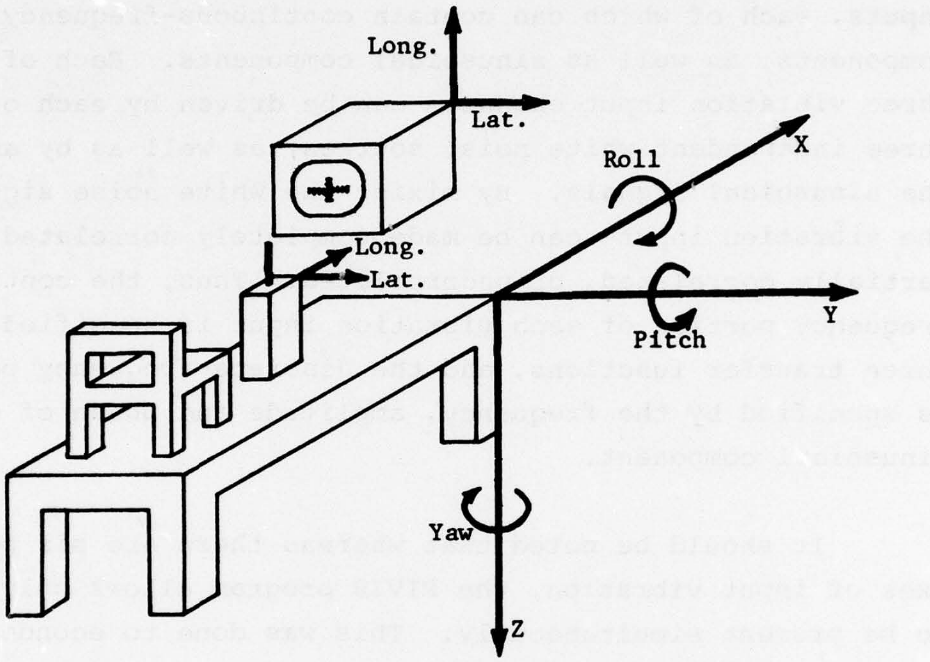

Figure 2. Six Axes of Platform/Pilot Vibration (X, Y, Z, Roll, Pitch, Yaw) and Two Axes of Stick/Display Vibration (Lateral, Longitudinal)

techniques are employed to predict biodynamic response measures. This was done to simplify the intermixing of empirical and theoretical models of biodynamic responses.

3.1.1 Vibration Inputs

Figure 3 illustrates the generation of the vibration input signals. The user can specify up to three vibration inputs, each of which can contain continuous-frequency components, as well as sinusoidal components. Each of the three vibration input channels can be driven by each of the three independent white noise sources, as well as by any of the sinusoidal signals. By mixing the white noise signals, the vibration inputs can be made completely correlated, partially correlated, or uncorrelated. Thus, the continuous-frequency portion of each vibration input is specified by three transfer functions, and the discrete-frequency portion is specified by the frequency, amplitude and phase of each sinusoidal component.

It should be noted that whereas there are six possible axes of input vibration, the PIVIB program allows only three to be present simultaneously. This was done to economize on the program storage requirements.

It is assumed that the vibration is at frequencies beyond the effective tracking bandwidth of the pilot/vehicle system. This assumption allows us to partition computations of stick feedthrough and tracking performance.

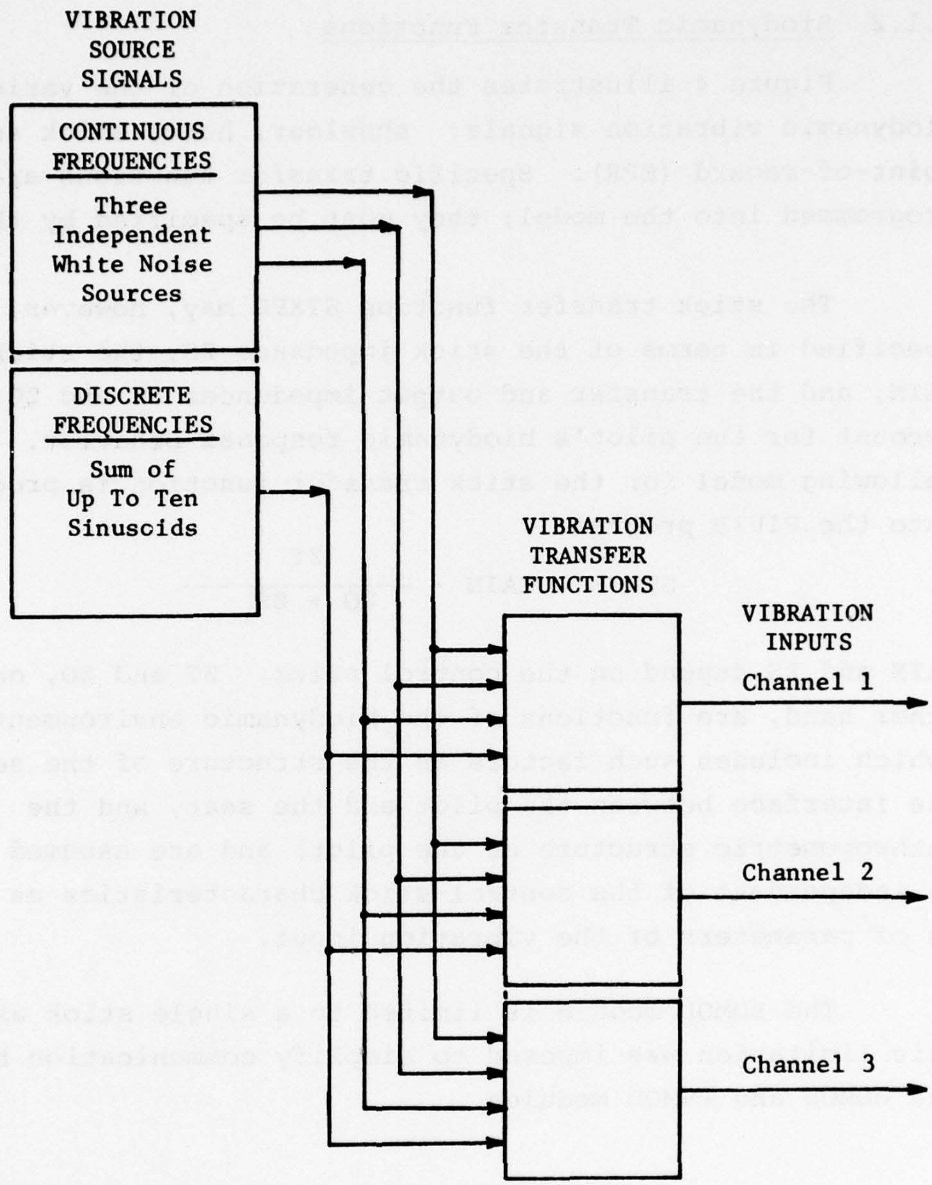

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Figure 3. Generation of the Vibration Input Signals

3.1.2 Biodynamic Transfer Functions

Figure 4 illustrates the generation of the various biodynamic vibration signals: shoulder, head, stick and eye-point-of-regard (EPR). Specific transfer functions are not programmed into the model; they must be specified by the user.

The stick transfer function STXFR may, however, be specified in terms of the stick impedance ZS, the stick gain GAIN, and the transfer and output impedences ZT and ZO which account for the pilot's biodynamic response behavior. The following model for the stick transfer function is programmed into the PIVIB program:

$$\mathrm{STXFR} = \mathrm{GAIN} \cdot \frac{\mathrm{ZT}}{\mathrm{ZO} + \mathrm{ZS}} \tag{1}$$

GAIN and ZS depend on the control stick. ZT and ZO, on the other hand, are functions of the biodynamic environment (which includes such factors as the structure of the seat, the interface between the pilot and the seat, and the anthropometric structure of the pilot) and are assumed to be independent of the control-stick characteristics as well as of parameters of the vibration input.

The BDMOD module is limited to a single stick axis. This limitation was imposed to simplify communication between the BDMOD and PVMOD modules.

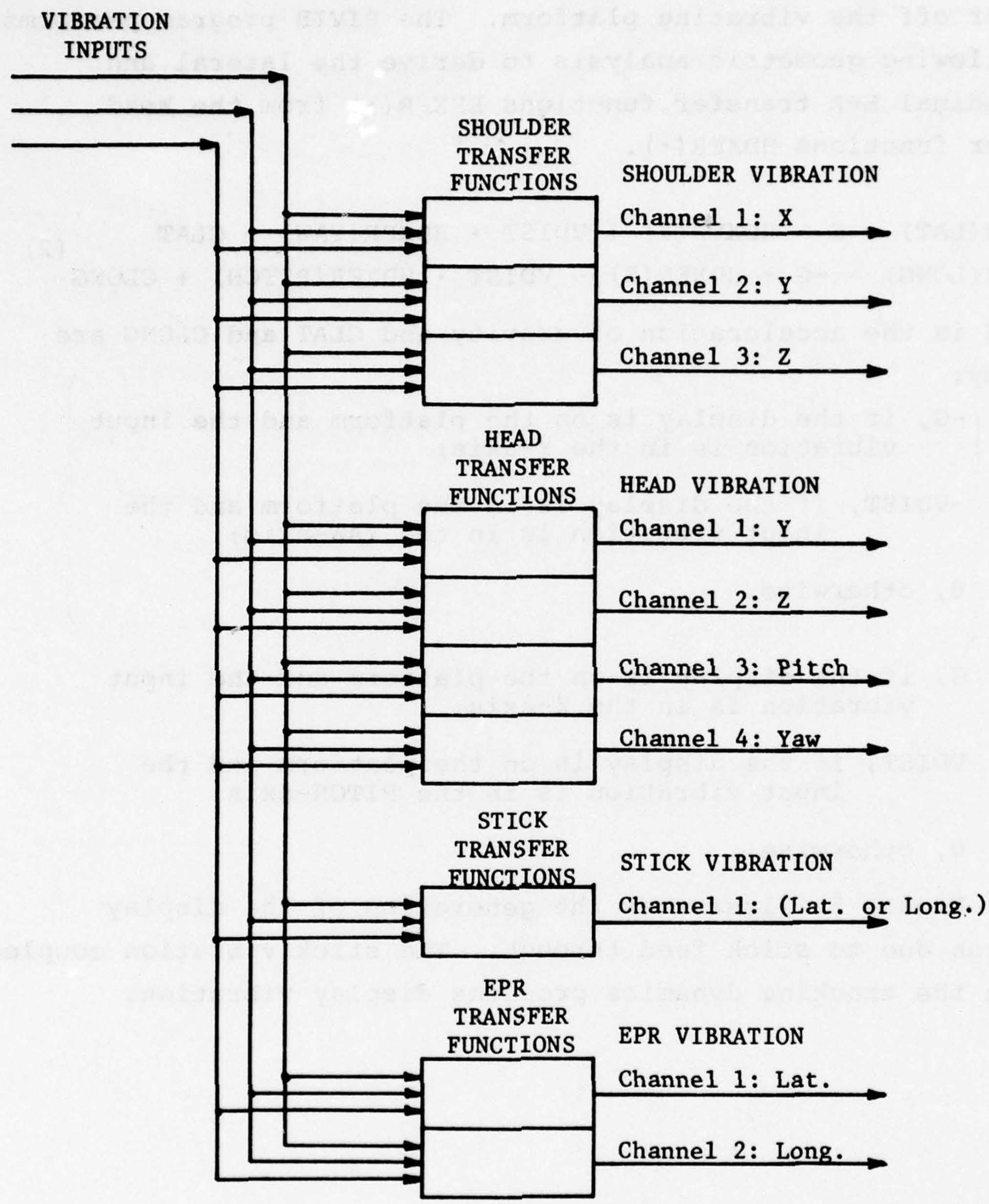

Figure 4. Generation of the Biomechanical Vibrations: Shoulder, Head, Stick, and Eye-Point-of-Regard (EPR)

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The EPR transfer function EPXFR is specified merely by specifying the viewing distance VDIST and whether the display is on or off the vibrating platform. The PIVIB program performs the following geometric analysis to derive the lateral and longitudinal EPR transfer functions EPXFR(·) from the head transfer functions HDXFR(·).

$$\begin{aligned} \mathrm{EPXFR(LAT)} &= \mathrm{G} \cdot \mathrm{HDXFR(Y)} + \mathrm{VDIST} \cdot \mathrm{HDXFR(YAW)} + \mathrm{CLAT} \\ \mathrm{EPXFR(LONG)} &= -\mathrm{G} \cdot \mathrm{HDXFR(Z)} - \mathrm{VDIST} \cdot \mathrm{HDXFR(PITCH)} + \mathrm{CLONG} \end{aligned} \tag{2}$$

Where G is the acceleration of gravity and CLAT and CLONG are given by:

$$\mathrm{CLAT} = \begin{cases} -\mathrm{G}, & \text{if the display is on the platform and the input vibration is in the Y-axis;} \\ -\mathrm{VDIST}, & \text{if the display is on the platform and the input vibration is in the YAW-axis;} \\ 0, & \text{otherwise.} \end{cases}$$

$$\mathrm{CLONG} = \begin{cases} \mathrm{G}, & \text{if the display is on the platform and the input vibration is in the Z-axis;} \\ \mathrm{VDIST}, & \text{if the display is on the platform and the input vibration is in the PITCH-axis;} \\ 0, & \text{otherwise.} \end{cases}$$

Figure 5 illustrates the generation of the display vibration due to stick feed through. The stick vibration coupled through the tracking dynamics produces display vibration.

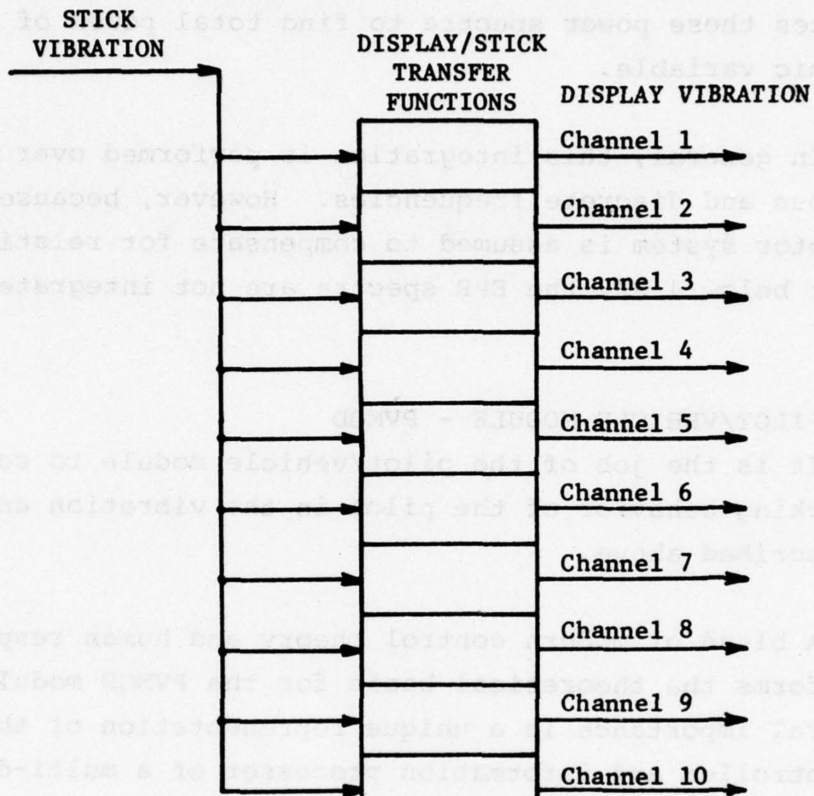

Figure 5. Generation of the Display Vibration due to Stick Feedthrough

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3.1.3 Biodynamic Response

Once the vibration inputs and the biodynamic transfer functions are specified, the PIVIB program computes the vibration power spectra of all biodynamic variables, and integrates these power spectra to find total power of each biodynamic variable.

In general, this integration is performed over all continuous and discrete frequencies. However, because the occulomotor system is assumed to compensate for relative movement below 4 HZ, the EPR spectra are not integrated below 4 HZ.

3.2 PILOT/VEHICLE MODULE - PVMOD

It is the job of the pilot/vehicle module to compute the tracking behavior of the pilot in the vibration environment described above.

A blend of modern control theory and human response theory forms the theoretical basis for the PVMOD module. Of central importance is a unique representation of the human as a controller and information processor of a multi-degree-of-freedom system. References 2 and 3 contain the technical details of BBN's man/machine modelling efforts, and they provide a background for understanding how human limitations are incorporated into the analysis tool provided by the PVMOD module.

Figure 6 shows a block diagram of the pilot/vehicle model which forms the basis of the PVMOD module. The major components of this model are discussed below. Additional details of this model may be found in References 1-7.

3.2.1 Vehicle Dynamics

A linearized description of the tracking dynamics is a prerequisite for applying the program. These dynamics include those of the controlled element, any actuator dynamics that may be significant, and dynamics associated with the generation of external disturbances. The linear dynamical equations are written in the general state variable format:

$$\dot{\underline{x}}(t) = \underline{A}\ \underline{x}(t) + \underline{B}\ \underline{u}(t) + \underline{E}\ \underline{w}(t),$$

where $\underline{x}(t)$ is an n_x vector of system states, $\underline{u}(t)$ is an n_u vector of pilot-generated control inputs, and $\underline{w}(t)$ is an n_w vector of random inputs. The values of n_x, n_u depend on the problem and the matrices $\underline{A}$, $\underline{B}$, and $\underline{E}$ must be of commensurate dimensions. Furthermore, the PVMOD module assumes that the states are ordered, and that the matrices are structured, so that the first n_c states are associated with the random disturbances and constitute "noise-shaping" filters with appropriate dynamics to give the desired spectral characteristics. The random input $\underline{w}(t)$ is a zero mean, Gaussian, white-noise with autocovariance $\underline{WD}$.

3.2.2 Display Variables

The pilot has available certain displayed information upon which he bases his control actions. These quantities, represented by the n_y vector $\underline{y}(t)$, are linear combinations of

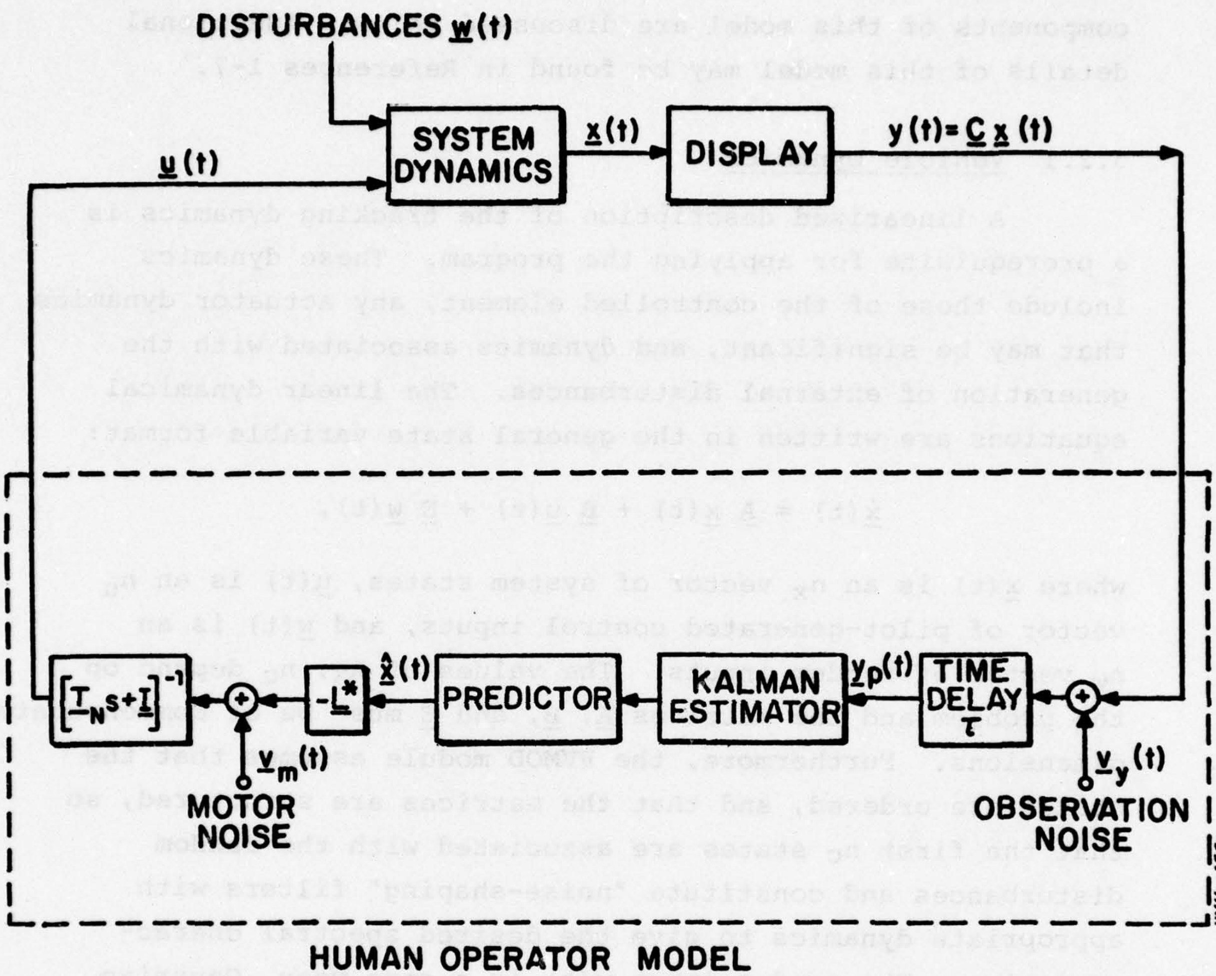

Figure 6. Overall Block Diagram of the Pilot/Vehicle Model

the state and control variables. Thus:

$$\underline{y}(t) = \underline{C}\ \underline{x}(t) + \underline{D}\ \underline{u}(t) \tag{4}$$

3.2.3 Model of the Pilot

For purposes of this discussion, it is convenient to consider the model of the pilot as being comprised of three parts (See Figure 6):

1) An "equivalent" perceptual model that translates the displayed variables $\underline{y}(t)$ into delayed, "noisy" perceived variables $\underline{y}_p(t)$ via the relation

$$\underline{y}_p(t) = \underline{y}\ (t - \tau) + \underline{V}_y\ (t - \tau) \tag{5}$$

where τ is an "equivalent" perceptual delay, and $\underline{V}_y$ is an "equivalent" observation noise vector. The use of the word "equivalent" in this context is to emphasize that the parameters can be lumped representations of a variety of limitations that current measurement techniques may not be able to identify separately.

2) An estimation and control generation process that consists essentially of a Kalman filter, a least mean-squared predictor, and a set of optimal control processing and compensation behavior.

3) An "equivalent" motor or output model that accounts for possible bandwidth limitations of the human and his inability to generate controls $\underline{u}_c$ are transformed into the control inputs $\underline{u}$ via the transformation:

$$\underline{\tau}_n\ \dot{\underline{u}}(t) + \underline{u}(t) = \underline{u}_c(t) + \underline{V}_u(t) \tag{6}$$

where $\underline{\tau}_n$ is an "equivalent" neuro-motor lag (which arises mathematically as a result of a including a control rate term in the controller's cost functional) and $\underline{V}_u$ is an "equivalent" motor noise vector.

3.2.3.1 Human Limitations

The time delay, observation noise, motor noise, and to some extent, the neuro-motor lag parameters of the model represent inherent human limitations which cannot be optimized. It is assumed that these parameters depend primarily on the interaction of the controller with the environment, and not on the specifics of the control task. In addition, the PIVIB program explicitly incorporates the effects of the vibration environment on the human's limitations. In particular, the PVMOD module includes a vibration interface submodule VBINT, in which the human's limitations are adjusted to account for the effects of vibration. The nature of these limitations in both the static and vibration cases is described below.

Neuromotor Lag: τ_n

Values of the neuromotor lag τ_n have typically been between 0.08 and 0.10 seconds. τ_n has not been found to be affected by vibration.

Perceptual Time Delay: τ

Values of the perceptual time delay τ in the static case have typically been in the range of 0.15 to 0.20 seconds. In the vibration case, the following empirical relationship has been found to hold:

$$\tau = \tau_o + K_\tau \text{ (RMSSH/RMSSTK)} \qquad (7)$$

where τ_o is the static value of time delay, K_τ is a constant equal to about 0.1;* RMSSH is the total rms shoulder acceleration, and RMSSTK is the rms control input (either force or displacement, depending on the type of stick).

Observation Noise: VY

The components of the observation noise vector are assumed to be independent, Gaussian, and sufficiently wideband so as to be considered white-noise processes. The variance of the observation noise is assumed to scale with the variance of the associated display output, modified by threshold and residual noise effects. In particular, it is assumed that the observation noise variances VY_i are given by:

$$VY_i = (PY/AT_i) \frac{Var(y_i)}{FTH(Var(y_i), TH_i)} + RS_i^2 \tag{8}$$

where PY is the base observation noise scale factor (or "noise/signal ratio") for full attention; AT_i is the attention factor, $Var(y_i)$ is the variance of the display output, TH_i is the threshold, FTH is the describing function gain of a threshold device, and RS_i is the rms value of the residual noise.

The magnitude of the base observation noise/signal ratio PY has been found to be invariant over a wide range of system dynamics and input noise spectra, which suggests that it is primarily a human-related, and not a system-related parameter. Typically for highly trained subjects the noise ratio is approximately 0.01π, which is equivalent to a normalized power density level of -20dB when defined for positive frequencies only.

*This figure applied to the force stick where RMSSH is in g's and RMSSTK is in lbs. For more details see Ref. 1.

The attention factor AT_i varies from one for full attention to zero for no attention. For most displays it is assumed that the controller can extract both position and rate, or the first derivative, information from a single display indicator, but he cannot extract higher derivatives. Thus, if an operator is devoting one-half his attention to a particular display, the attention factors associated with both the position and rate from that display would both be 0.5. Furthermore, it is assumed that the sum of the attention factors from all the physically separate displays is one.

The describing function gain of a threshold device, FTH in Equation 8, is given by:

$$FTH(\sigma^2, TH) = \frac{2}{\sqrt{\pi}} \int_{-\infty}^{-TH/\sqrt{2\sigma^2}} e^{-x^2}\, dx, \qquad (9)$$

where TH is the threshold and σ^2 is the variance of the input to the threshold device. This factor is used to account for threshold-type phenomena associated with viewing the display. However, so-called indifference thresholds (related to acceptable or allowable errors) will have an indistinguishable effect. Essentially, its effect is to cause the observation noise covariance to become greater as the signal becomes smaller relative to the threshold. It is important to note that the degradation is continuous and that it is, in effect, a statistical threshold. This is consistent with concepts in human signal detectability [8]. Note also that for signals well above threshold, σ>>TH, the function FTH is approximately unity.

The residual noise variance RS in Equation 8 is similar in effect to a threshold, but it can be viewed as a separate parameter and is normally used to account for the observed degradation in performance that results from lack of reference indicators [9].

The primary effect of pilot vibration on observation noise, is through the eye-point-of-regard, EPR, motion. This effect is assumed to be direction-specific as well as derivative-specific. For example, the perception of the lateral displacement of a display variable is assumed to be affected primarily by the EPR lateral displacement and secondarily by the EPR longitudinal displacement. Similarly, the perception of the lateral velocity of that display variable is assumed to be affected primarily by the EPR lateral velocity, etc. Accordingly, the VBINT submodule incorporates the following expression for residual noise:

$$RS_i = RS0_i + KLAT_i \cdot MSEPR(LAT) + KLONG_i \cdot MSEPR(LONG). \quad (10)$$

The constants KLAT and KLONG are supplied by the user*, along with the nature of the display variable: displacement, velocity or acceleration. The terms MSEPR(LAT) and MSEPR(LONG) are the mean-squared EPR displacement, velocity or acceleration (depending on the nature of the display variable) in the lateral and longitudinal directions.

Under ideal conditions, then, in the absence of vibration, with well scaled and easily read displays, and with signals well above threshold, the observation noise variances are given by

$$VY_i = (PY/AT_i)\ [Var(y_i)]. \quad (11)$$

* Note that while MSEPR will be in inches, in/sec or in/sec^2 (depending on the nature of the display), and RS_i is typically in problem units (e.g. degrees of pitch angle). Thus the constants KLAT and KLONG must appropriately convert between these units.

Motor Noise: VU

The other source of human randomness is motor noise. Like the observation noise, its components are assumed to be independent, Gaussian, and sufficiently wideband so as to be considered white-noise processes.

In the static case, the variance of the motor noise is assumed to scale with the variance of the associated commanded control

$$VU_i = PU_i \, [\mathrm{Var}(u_{ci})] \tag{12}$$

where PU_i is the motor noise scale factor (or "noise/signal ratio"), and Var (u_{ci}) is the variance of the commanded control. A value of PU_i of about 0.003π (equivalent to a normalized power density level of -25dB) has been found to provide a good match to experimental data.

In the vibration case, the motor noise was found not to scale with variance of the commanded control. Instead, the following empirical relationship has been found to hold:

$$VU_i = K_{v_u} \, (\mathrm{RMSSH/RMSSTK}) \tag{13}$$

where K_{v_u} is a constant equal to about 0.02*, and RMSSH and RMSSTK are the RMS shoulder and stick accelerations respectively, the same quantities as in the expression for τ in the vibration case, Equation 7.

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* This figure applies to a force stick where RMSSH is in g's and RMSSTK is in lbs. For more details see Ref. 1.

3.2.3.2 The Control Process

The optimal estimator, predictor, and controller represent the set of adjustments or adaptations by which the human controller tries to optimize his behavior given his limitations. The general expressions for these model elements, which can be derived according to well-defined model rules, are given in Reference 2.

The controller is assumed to adopt a response strategy to minimize the following weighted sum of state, output and control variables:

$$J(u)=E\left\{\sum_i QX_i \cdot x_i^2 + QY_i \cdot y_i^2 + QU_i \cdot u_i^2 + QR_i \cdot \dot{u}_i^2\right\} \quad (14)$$

conditioned on the observations $\underline{y}_p$.

The cost on control rate represents, in part, a subjective penalty imposed by the controller on making rapid control motions. In addition, this term may account indirectly for physiological limitations on the operator's bandwidth. The inclusion of this term in the cost functional results in the lag $\underline{\tau}_n$ (often associated with the neuromuscular system) appearing in the optimal controller (Equation 6).

For a given set of cost functional weightings (QX_i, QY_i, QU_i, and QR_i), the controller computes a corresponding set of feedback gains, $\underline{L}^*$. The "commanded" control input, $\underline{u}_c$ in Equation 6, is then calculated by the controller according to:

$$\underline{u}_c(t) = -\underline{L}^* \cdot \hat{\underline{x}}(t), \quad (15)$$

where $\hat{\underline{x}}(t)$, the output of the Kalman filter and predictor (see Figure 6), is the controller's best estimate of the current system state. Thus, combining Equations 6 and 15, we see that the actual control input, $\underline{u}(t)$, satisfies

$$\underline{\tau}_n \, \underline{u}(t) + \dot{\underline{u}}(t) = \underline{L}^* \, \hat{\underline{x}}(t) + \underline{V}_u. \tag{16}$$

3.2.3.3 Frequency Domain Measures

Because the structure of the human operator portion of the pilot/vehicle model is linear and time-invariant, it can be represented in the frequency domain by a transfer matrix relating $\underline{y}$ to $\underline{u}$, i.e.

$$\underline{u}(s) = \underline{H}(s) \, \underline{y}(s). \tag{17}$$

The expression for $\underline{H}(s)$ in terms of model parameters is rather complicated and may be found in Reference 4. It is possible, therefore, to predict human operator describing functions that are equivalent to those that could be measured in an experiment. In particular, it is possible to compute the input-correlated (non-remnant) portions of signals at various points in the control loop, and in an experiment these quantities could be measured. The ratio of these signal portions at a control and at a display is termed an "equivalent" describing function, and the ratio of these protions at two displays is termed a "display-equivalent: describing function.

Knowing $\underline{H}(s)$ the remnant processes V_y and V_u can be reflected to an equivalent noise process injected on to any given output. The result of this manipulation is a prediction of a remnant spectrum that could be measured in an experiment.

This remnant spectrum might be normalized, i.e. expressed as a fraction of the total signal spectrum at that output.

Finally, since the system is linear, any signal can be considered as the sum of two parts: one arising from $\underline{w}(t)$, related to the input driving noise, and the other arising from the human's noise sources $\underline{V}_y$ and $\underline{V}_u$, which are related to the remnant. Thus the power spectrum of any system state, of any output, or of the control can be predicted.

The PVMOD module includes a Frequency Domain Submodule FDREP which computes these frequency domain measures: describing functions, remnant spectra, and signal spectra.

4. PROGRAM CONTROL

The operation of the program is governed by the program control cards in the data deck. The detailed structure of the data deck is described later in Section 7 of this manual dealing with the program operating instructions.

4.1 EXEC MODULE - VEXEC

When the PIVIB program is started, control automatically enters the VEXEC module. After specifying a title, the user calls either the BDMOD module or the PVMOD module. Once the program is executing either module, an "END" control card returns the program back to the VEXEC module. the two modules can then be called sequentially. The program is halted by means of an "EXIT" card supplied to the VEXEC module.

4.2 BIODYNAMIC RESPONSE MODULE - BDMOD

When the program enters the BDMOD module, the user specifies a subtitle, and then calls any of the BDMOD submodules.

4.2.1 FREQS Submodule

Because all vibration and biodynamic variables are specified in the frequency domain, and frequency domain integration techniques are employed to predict biodynamic response measures, when the BDMOD module is entered for the first time, the user must first call the FREQS submodule to specify all the frequencies required for the biodynamic analysis. If there are continuous-frequency vibration inputs, the user specifies the frequency range over which the vibration is assumed to be important. The program then

automatically divides this frequency range into 1/4 octave intervals. If there are sinusoidal (discrete-frequency) vibration inputs, the user identifies the frequencies for all the components.

4.2.2 VIBR Submodule

Following the call to the FREQS submodule, the user can then call the VIBR submodule to specify the vibration environment. The generation of the vibration input signals was illustrated in Figure 3. The transfer functions which specify the continuous-frequency portion of the vibration inputs may themselves be specified in any of three modes: GNPH, samples of the gain and phase at a number of frequencies; POLEO, analytically in terms of poles, zeroes, and a gain constant; or POLYS, analytically in terms of numerator and denominator coefficients for polynomials in "s"; or they may be nulled, NULL. The discrete-frequency portion of each vibration input is specified simply by giving the frequency, amplitude and phase of each sinusoidal component. In addition, the user can and should identify the vibration axis corresponding to each vibration input channel.

4.2.3 BIOTR Submodule

Following the call to the VIBR submodule, the user can then call the BIOTR submodule to specify the biodynamic transfer functions. In general, the biodynamic transfer functions may be specified in any of three modes: GNPH, samples of the gain and phase at a number of frequencies; POLEO, analytically in terms of poles, zeroes, and a gain

constant; or POLYS, analytically in terms of numerator and denominator coefficients for polynomials in "s", or they may be nulled, NULL. The generation of the various biomechanical vibrations, shoulder, head, stick and eye-point-of-regard (EPR), was illustrated in Figure 4. The stick transfer function STXFR may alternatively be specified in terms of the stick impedance ZS, the stick gain GAIN, and the transfer and output impedances ZT and ZO, according to Equation 1. These impedances themselves may be specified in any of the above three modes.

The user specifies the EPR transfer function merely by specifying the viewing distance and whether the display is on or off the table. The program automatically performs geometric analysis to derive the EPR transfer function from the head transfer function. (The occulomotor system is assumed to compensate for relative movement below 4 Hz.)

It should be noted that each vibration channel of shoulder, head and EPR vibration is permanently associated with a particular axis of vibration, as shown in Figure 4. For example, shoulder vibration channel 1 always corresponds to Pitch-axis vibration, and EPR vibraton channel 2 always corresponds to Longitudinal-axis vibration.

On the other hand, the stick vibration channel may be associated with either Lateral-axis or Longitudinal-axis vibration. Thus, in the BIOTR submodule, in addition to specifying all the biodynamic transfer functions, the user has the facility to specify the vibration axis of the stick.

The generation of the display vibration due to stick feedthrough was illustrated in Figure 5. This transfer function, which is determined by the vehicle dynamics, may be specified by the user in any of the above three modes. In addition, the user can specify the identities of each of these ten display channels.

Theoretically, these transfer functions could be computed from the state-variable description supplied to the PVMOD module. However, it was decided to keep the two modules as independent as possible to keep the program flexible for future modifications.

4.2.4 BDOUT Submodule

The BDOUT Submodule is used to specify the biodynamic quantities for the program to print out. The default condition, is to print out all the non-zero biodynamic transfer functions and power spectra. In this submodule, the user may specify that only certain transfer functions or spectra be output, or that only the total power in a biodynamic spectrum be output.

4.2.5 BCOMP Submodule

Following the calls to the other four submodules, the user then calls the BCOMP submodule for the purpose of computing and printing all the specified biodynamic quantities. BCOMP operates automatically; it requires no additional data cards. Its operation is divided into the following seven parts, each handled by its own subroutine.

4.2.5.1 CSTXFR - This subroutine determines if any of the stick transfer functions are missing. If so, the missing transfer functions are computed from the transfer, output, and stick impedances (ZT, ZO, and ZS), if they are available, and the stick gain. It should be stressed that only missing (i.e. null) stick transfer functions are computed from the impedances. Consequently, if the user wants to change an impedance and recompute the stick transfer function, he must null the current stick transfer function.

4.2.5.2 CEPXFR - This subroutine computes the eye-point-of-regard (EPR) transfer functions based on the head transfer functions.

4.2.5.3 PRTXFR - This subroutine prints all the specified transfer functions.

4.2.5.4 SPCPOW - This subroutine computes all the complex spectra due to each of the three independent noise sources which form the continuous-frequency portion of the vibration inputs, as well as the spectra due to the sinusoidal components of the vibration input. Then these complex spectra are summed to find the total power spectra due to all the vibrations sources, combined.

4.2.5.5 INTPOW - This subroutine integrates all the power spectra to find the total power in each of the biodynamic signals.

4.2.5.6 PRTPOW - This subroutine prints all the specified power spectra along with the total integrated power.

4.2.5.7 STORPV - This subroutine stores in a special common block all the information to be transmitted to the PVMOD module.

4.3 PILOT/VEHICLE MODULE - PVMOD

When the program enters the PVMOD module, the user specifies a subtitle, and then either specifies various pilot/vehicle (PV) parameters, or calls any of the PVMOD submodules. (See Figure 1.)

4.3.1 Specifying P/V Parameters

When the PVMOD module is entered, the user normally first specifies various P/V parameters. These parameters are summarized in Table 1. A parameter that is to be specified is first identified by its "Parameter ID Code", followed by the value of the parameter (matrix, vector, or scalar).

4.3.2 VBINT Submodule

In addition to specifying the ordinary P/V parameters, the user can also call the VBINT submodule to specify sets of parameters regarding the interaction of the Biodynamic and the Pilot/Vehicle Modules. These VBINT parameters sets are summarized in Table 2.

4.3.3 PCOMP Submodule

Once the user has specified the P/V parameters, and called the VBINT submodule (if desired), he can call the PCOMP submodule to perform the Pilot/Vehicle computations. This submodule computes the predicted variance and standard deviation of all states, controls, and outputs, as well as the predicted variance and standard deviation of the pilot's estimates and estimation errors of all states, controls, and outputs. In addition, if the VBINT module was initialized, the vibration-feedthrough incremented scores are also computed.

TABLE 1

PILOT/VEHICLE PARAMETERS

ID CODE	PARAMETERS
DIMEN	Problem Dimensions NX = number of total system states NX1 = number of noise-shaping states NU = number of control system inputs NW = number of random noise sources NY = number of displayed outputs
A, B, C, D, E	System Dynamics Matrices where: $\dot{\underline{x}} = \underline{A}\,\underline{x} + \underline{B}\,\underline{u} + \underline{E}\,\underline{w}$ $\underline{y} = \underline{C}\,\underline{x} + \underline{D}\,\underline{u}$
	Cost Functional Weightings
QY	Outputs
QX	States
QU	Controls
QR	Control rates
TD	Human's Time Delay - τ
WD	Random Noise Covariance
TH	Thresholds - TH_i
RS	Residual Noise - RS_i
PU	Motor Noise Ratio
VU	Equivalent Additive Motor Noise
PY	Observation Noise Ratio
VY	Equivalent Additive Observation Noise
ATTN	Attention - AT_i
FREQ	Frequencies for FDREP

TABLE 2

VBINT PARAMETER SETS

CODE	PARAMETERS
EPR	Parameters relating residual noise variance to relative EPR motion $KLAT_i$ and $KLONG_i$ (see Eq 10)
STICK	IDSTIK - Type of stick (displacement or force)
	NYSTK - Identity of the display channel corresponding to the stick
	RMSSTK - First guess of RMS stick displacement
TD	τ_o - Static time delay
	K_τ - Time delay vibration parameter (See Eq 7)
	TDTOL - Tolerance for computing the time delay
KVU	K_{vu} - Motor noise vibration parameter (See Eq 13)
	VUTOL - Tolerance for computing the motor noise
RESET	Do not do VBINT calculations
ZZZZZ	End VBINT initialization

Once these computations are completed, a summary of the PVMOD and VBINT parameters are printed, along with the results of the computations.

4.3.4 FDREP Submodule

Once the user has called the PCOMP submodule, he can then call the FDREP submodule to compute and print various describing functions, pilot remnants, as well as signal spectra. The available FDREP functions are summarized in Table 3. Brief descriptions of selected FDREP functions may be found in Section 3.2.3.3 of this manual; more complete descriptions are available in Reference 10.

TABLE 3

FDREP FUNCTIONS

	CODE	NAME
Describing Functions	I	Internal Describing Function
	E	Equivalent Describing Function
	D	Display-Equivalent Describing Function
	C	Circulatory Describing Function
	V	Vehicle Open-Loop Describing Function
	M	Multiple Describing Function
Remnant Spectra	U	Un-Normalized Remnant Spectrum
	N	Normalized Remnant Spectrum
Power Spectra	X	Power Spectrum of a State
	Y	Power Spectrum of an Output
	U	Power Spectrum of a Control

5. PROGRAM INPUTS

The user provides information to the program via a set of cards known as the data deck. The rules for structuring these cards is described in this section. In particular, the rules are given for entering integers, real numbers, alphanumeric data, vectors, matrices, transfer functions, and discrete transfer functions (used to specify the discrete vibration environment).

Each card is divided into one or more data fields, and each field contains one of the following three types of input data:

> <u>Integer</u> -- a fixed-point number written without a decimal point. A negative number must be preceded by a minus sign; a positive number may be preceded by a plus sign. All integers must be right-adjusted within the allotted field. The size of the field is usually 5 characters, I5, and occasionally 10 characters, I10.
>
> <u>Real Number</u> -- a floating-point number written with a decimal point. The number may be situated anywhere within its allotted field, although it is recommended that they be right-justified. The size of the field is always 10 characters, F10.0. If a decimal exponent is used, the exponential part (denoted by the letter E followed by a signed integer) must be right-adjusted within the field. The column following the letter E must not be blank, but it may be zero.
>
> <u>Alphanumeric</u> -- any combination of alphanumeric and numeric characters. Alphanumeric data must be <u>left</u>-justified within its allotted field. The size of the field is usually 5 characters, A5, and occasionally 10 or more characters, A10.

Vectors and matrices are input according to the following rules.

Vectors -- Each card has up to eight (8) fields of ten (10) characters, each associated with a number. The numbers are generally real, but occasionally are integers. If a vector contains more than eight (8) numbers, continue on a second card. If the last number occurs in the middle of a card, the remainder of the card is left blank.

Matrices -- Matrices are input one row at a time, with each row being input as a separate vector. Thus, each matrix row begins on a new card.

Transfer functions are input in any of the following four forms: gains and phases (GNPH), poles and zeroes (POLE0), numerator and denominator polynomials in s (POLYS), or null (NULL). The first card identifies the form of the transfer function.

Transfer Function Identifier Card

Columns 1- 5: Alphanumeric Identifier LFORM
Columns 6-10: Integer N1
Columns 11-15: Integer N2
Columns 16-20: Integer N3
Columns 21-25: Integer N4

Identifer LFORM

GNPH : Gains and Phases are specified at N1 frequencies
POLE0: One gain, N1 simple poles, N2 complex poles, N3 simple zeroes, and N4 complex zeroes are specified.
POLYS: The numerator is specified by a polynomial of order N1 and the denominator is specified by a polynomial of order N2.
NULL : the transfer function is set to zero.

Following the transfer function identifier card are one or more data cards. The nature of the cards depend on the transfer function form.

Transfer Function Data Cards (depends on which form)

GNPH:

First Card(s)	:	real N1 vector - frequencies
Next Card(s)	:	real N1 vector - gains
Next Card(s)	:	real N1 vector - phases

POLE0:

First Card	:	real number - gain
Next Card(s)	:	If N1 > 0, real N1 vector - simple poles
Next Card(s)	:	If N2 > 0, real N2 vector - natural frequencies of complex poles
Next Card(s)	:	If N2 > 0, real N2 vector - damping ratios of complex poles
Next Card(s)	:	If N3 > 0, real N3 vector - simple zeroes
Next Card(s)	:	If N4 > 0, real N4 vector - natural frequencies of complex zeroes
Next Card(s)	:	If N4 > 0, real N4 vector - damping ratios of complex zeroes

POLYS:

First Card(s)	:	real (N1 + 1) vector - Numerator coefficients in ascending order
Next Card(s)	:	real (N2 + 1) vector - Denominator coefficients in ascending order

NULL:

No data cards required.

Finally, discrete transfer functions are input in either of the following two forms: gains and phases (GNPH) or null (NULL). The first card identifies the form of the discrete transfer function.

Discrete Transfer Function Identifier Card

Columns 1- 5 : Alphanumeric Identifier LFORM

Columns 6-10 : Integer N1

Identifier LFORM

GNPH: Gains and Phases are specified at N1 frequencies.

NULL: The transfer function is set to zero.

Following the discrete transfer function identifier card are several data cards. The nature of these cards depends on the discrete transfer function form.

Discrete Transfer Function Data Cards (depends on which form)

GNPH:

First Card(s) : Integer N1 vector - the indices of the particular discrete frequencies for which the discrete transfer function is non-zero. Note that at all other frequencies, the discrete transfer function will be set to zero (null).

Next Card(s) : Real N1 vector - The gains at the above specified frequencies

Next Card(s) : Real N1 vector - The phases at these frequencies.

NULL:

No data cards required.

6. PROGRAM OUTPUTS

PIVIB generates two classes of outputs, both of which are written on the file OUTPUT for listing on the line printer. One class of outputs is generated by the Biodynamic Response Module, and the other class is generated by the Pilot/Vehicle Module.

6.1 BIODYNAMIC RESPONSE MODULE - BDMOD

The BDMOD module prints all the specified transfer functions followed by all the specified power spectra along with the rms vibration measures.

6.2 PILOT/VEHICLE MODULE - PVMOD

The PVMOD module first prints a summary of all the P/V parameters. The motor and observation noise ratios are then printed, followed by the variance and standard deviation of all the system states, controls and outputs. The components of the cost functional J(u) and its total value are also printed. Next, the variance and standard deviation of the pilot's estimates and estimation errors are printed.

If the VBINT submodule was initialized, the VBINT parameters are printed followed by the vibration - feed-through incremented scores.

If any calls to the FDREP submodule have been made, the results of the FDREP calculations are then printed.

7. PROGRAM OPERATING INSTRUCTIONS

The operation of the PIVIB program is governed by the program control cards in the data deck. The user calls a particular program module (or sub-module) by inserting into the data deck a program control card which identifies the module, followed by the data cards pertaining to that module. The structures of the program control cards and the various types of data cards are described below.

The first card in the data deck must be a title card which specifies an overall title for the data deck.

<u>Title Card</u>:

Columns 1-80: Alphanumeric Title

Once the title card is read, the program automatically enters the VEXEC module.

7.1 EXEC MODULE - VEXEC

Upon entering the VEXEC module, the program reads a program control card.

<u>VEXEC Program Control Card</u>

Columns 1-5: Alphanumeric Identifier

- BDMOD: Call the BDMOD module
- PVMOD: Call the PVMOD module
- EXIT : Exit from the PIVIB program

The program then enters the specified module or exits from the PIVIB program.

7.2 BIODYNAMIC RESPONSE MODULE - BDMOD

Upon entering the BDMOD module, the program reads a subtitle card which specifies a title for the following BDMOD operations.

Subtitle Card:

Columns 1-80: Alphanumeric Subtitle

Once the subtitle card is read, the BDMOD module reads a program control card specifying a particular BDMOD submodule.

BDMOD Program Control Card:

Columns 1-5: Alphanumeric Identifier

FREQS:
VIBR :
BIOTR: Call the specified submodule
BDOUT:
BCOMP:
END : End BDMOD operations.
Return to the VEXEC module

Following the execution of the specified submodule, another BDMOD program control card is read. The program continues to execute the BDMOD submodule until it encounters an "END" control card. The data cards required by each of the BDMOD submodules is described below.

7.2.1 FREQS Submodule

The purpose of the FREQS submodule is to specify all the frequencies, continuous and discrete, required for the biodynamic analysis. The first card read by the FREQS submodule is an identifier card which determines which FREQS option is to be performed.

FREQS Option Identifier Card

Columns 1- 5: Alphanumeric Identifier
Columns 6-10: Integer NDFREQ

CONT :	Specify Continuous Frequencies
DISCR:	Specify Discrete Frequencies NDFREQ = No. of discrete frequency components.
ZZZZZ:	End FREQS operations. Return to the BDMOD module

Following the identifier card is a parameter card. The nature of the parameter card depends on which FREQS option is called.

FREQS Parameter Cards (depends on which option)

CONT option:

Columns 1-10: Real CFMIN
Columns 11-20: Real CFMAX
Columns 21-30: Integer KFSTP

CFMIN and CFMAX are the lower and upper bounds of the continuous-frequency range. This range is automatically divided into 1/4 octave intervals. KFSTP is the step size employed when printing the continuous-frequency BDMOD results. If KFSTP=1, each frequency is printed (1/4 octave) if KFSTEP=2, every other frequency is printed (1/2 octave), if KFSTEP=4, every fourth frequency is printed (1 octave); etc.

DISCR option:

The discrete frequencies are entered as an NDFREQ vector.

ZZZZZ option:

No parameter card.

After the parameter card is read, the program reads another option identifier card. The sequence is repeated until a ZZZZZ card is encountered.

7.2.2 VIBR Submodule

The purpose of the VIBR submodule is to specify the vibration environment, by specifying the vibration input/ source transfer functions (see Figure 3). The first card read by the VIBR submodule is an identifier card which determines which VIBR option is to be performed.

VIBR Option Identifier Card

Columns 1- 5 : Alphanumeric Identifier LFCN1
Columns 6-10 : Alphanumeric Sub-Identifier LFCN2
Columns 11-15 : Integer NUM1
Columns 16-20 : Integer NUM2

Option Identifier LFCN1

CONT : Specify a Continuous Frequency Vibration Transfer Function
DISCR: Specify a Discrete Frequency Vibration Transfer Function
IDENT: Specify the Axis of a Vibration Input Channel
ZZZZZ: End VIBR operations. Return to the BDMOD module

Option Sub-Identifier LFCN2

If LFCN1 = CONT, DISCR or IDENT, then LFCN2 may be any one of the following: (blank), SPC, or XFR. If LFCN1 = ZZZZZ, then LFCN2 must be (blank).

Integers NUM1 and NUM2

NUM1 = The vibration input channel number.
NUM2 = The vibration source channel number.

Following the VIBR option identifier card are one or more parameter cards. The nature of these cards depends on which VIBR option is called.

VIBR Parameter Cards (depends on which option)

CONT option:

The transfer function is entered in one of the four forms described in Section 5 of this manual: gains and phases (GNPH), poles and zeroes (POLE0), numerator and denominator polynomials in S (POLYS), or null (NULL).

DISCR option:

The discrete frequency components of the vibration inputs are entered in one of the two forms described in Section 5 of this manual: discrete gains and phases (GNPH), or null (NULL).

IDENT option:

Columns 1-5: Alphanumeric axis identifier LAX. LAX may be one of the following: X, Y, Z, ROLL, PITCH or YAW.

ZZZZZ option:

No parameter card

After the parameter cards are read, the program reads another option identifier card. The sequence is repeated until a ZZZZZ card is encountered.

7.2.3 BIOTR Submodule

The purpose of the BIOTR submodule is to specify the biodynamic transfer functions (see Figure 4). The first card read by the BIOTR submodule is an identifier card which determines which BIOTR option is to be performed.

BIOTR Option Identifier Card

Columns 1- 5: Alphanumeric Identifier LFCN1
Columns 6-10: Alphanumeric Sub-Identifier LFCN2
Columns 11-15: Integer NUM1
Columns 16-20: Integer NUM2

Option Identifier LFCN1

SHOUL: Specify a Shoulder/Vibration transfer function
STICK: Specify a Stick/Vibration transfer function directly or specify a transfer,output or stick impedance or a stick gain, or the identity of the stick/axis.
DISPL: Specify a Display/Stick transfer function or the identity of a Display channel.
HEAD : Specify a Head/Vibration transfer function
EYEPT: Specify an EPR/Vibration transfer function
ZZZZZ: End BIOTR operations. Return to the BDMOD module

Option Sub-Identifier LFCN2

If LFCN1 = SHOUL or HEAD, then LFCN2 may be either (blank) or XFR.

If LFCN1 = EYEPT or ZZZZZ, then LFCN2 must be (blank).

If LFCN1 = STICK, then LFCN2 may be any one of the following:

(blank): Specify a Stick/Vibration transfer function directly
XFR : Specify a Stick/Vibration transfer function directly
ZT : Specify a transfer impedance
ZO : Specify an output impedance
ZS : Specify the stick impedance
GAIN : Specify the stick gain
IDENT : Specify the identity of the stick axis.

If LFCN1 = DISPL, then LFCN2 may be any one of the following:

Blank: Specify a Display/Stick transfer function,
XFR : Specify a Display/Stick transfer function,
IDENT: Specify the identity of a display axis.

Integers NUM1 and NUM2

NUM1 = The transfer function output channel number
NUM2 = The transfer function input channel number

Following the BIOTR option identifier card are one or more parameter cards. The nature of these cards depends on which BIOTR option is called.

BIOTR Parameter Cards (depends on which option)

SHOUL, STICK, (STICK-ZT, STICK-ZO, STICK-ZS), DISPL or HEAD options:

The transfer function (or impedance) is entered in one of the four forms described in Section 5 of this manual: gains and phases (GNPH), poles and zeroes (POLE0), numerator and denominator polynomials in s (POLYS), or null (NULL).

STICK IDENT option:

Columns 1-5: Alphanumeric axis identifier LAX. LAX may be either LAT or LONG.

DISPL IDENT option:

Columns 1-5: Alphanumeric axis identifier LAX. LAX may be any 5 character identifier.

STICK GAIN option:

Columns 1-10: Real number

EYEPT option:

Columns 1- 5: Alphanumeric identifier LLOC
Columns 6-10: (blank)
Columns 11-20: (Real number VDIST)

LLOC may be either ON or OFF, specifying that the display is mounted either on or off the table.

VDIST specifies the viewing distance from the pilot to the display.

ZZZZZ option:

No parameter card

After the parameter cards are read, the program reads another option identifier card. The sequence is repeated until a ZZZZZ card is encountered.

7.2.4 BDOUT Submodule

The purpose of the BDOUT submodule is to specify the biodynamic quantities to be printed out. Since the default condition is to print out all the non-zero biodynamic transfer function and power spectra, the user normally need only specify those quantities which are not to be printed out. A call might also be made to the BDOUT submodule to request the printing of a quantity which was previously specified not to be printed.

The first card read by the BDOUT submodule is an identifier card which determines which BDOUT option is to be performed.

BDOUT Option Identifier Card

Columns 1- 5: Alphanumeric Identifier LFCN1
Columns 6-10: Alphanumeric Sub-Identifier LFCN2
Columns 11-15: Integer NUM1
Columns 16-20: Integer NUM2
Columns 21-25: Integer KOUTF

Option Identifier LFCN1

SHOUL: Specify the output of shoulder quantities
STICK: Specify the output of stick quantities
DISPL: Specify the output of display quantities
HEAD : Specify the output of head quantities
EPR : Specify the output of EPR quantities
VIBR : Specify the output of table vibration quantities
ZZZZZ: End BDOUT operations. Return to the BDMOD module.

Option Sub-Identifier LFCN2

If LFCN1 = SHOUL, DISPL, HEAD, EPR or VIBR, then LFCN2 may be any one of the following:

XFR: specify the output of the transfer function
SPC: specify the output of the power spectrum
POW: specify the output of the power spectrum

If LFCN1 = STICK, then LFCN2 may be any one of the following:

XFR: specify the output of a stick transfer function
SPC: specify the output of a stick power spectrum
POW: specify the output of a stick power spectrum
ZT : specify the output of the transfer impedance
ZS : specify the output of the stick impedance
ZO : specify the output of the output impedance

If LFCN1 = ZZZZZ, then LFCN2 must be (blank).

Integers NUM1 and NUM2

NUM1 = The transfer function or spectrum output channel number
NUM2 = The transfer function input channel number

Integer KOUTF

KOUTF specifies whether the particular biodynamic quantity will be output.

KOUTF = 0: The quantity will not be output
KOUTF = 1: The quantity will be output
KOUTF = 2: Only the total power will be output (applies only to a power spectrum)

No parameter cards are required by the BDOUT submodule. The option identifier cards are read one by one until a ZZZZZ card is encountered.

7.2.5 BCOMP Submodule

The purpose of the BCOMP submodule is to compute and print all the specified biodynamic quantities. The submodule operates automatically and requires no additional cards.

7.3 PILOT/VEHICLE MODULE - PVMOD

Upon entering the PVMOD module, the program reads a subtitle card which specifies a title for the following PVMOD operations.

Subtitle Card:

Columns 1-80: Alphanumeric Subtitle

Once the subtitle card is read, the PVMOD module reads a program control card specifying either a particular P/V parameter or a particular PVMOD submodule.

PVMOD Program Control Card:

Columns 1-5: Alphanumeric Identifier MCODE

If MCODE is a particular P/V parameter ID code (see Table 1 or below) then that parameter will be specified.

MCODE may also be one of the following:

```
VBINT:  Call the VBINT submodule
PCOMP:  Call the PCOMP submodule
FDREP:  Call the FDREP submodule
END  :  End PVMOD operations
        Return to the VEXEC module
```

Following the specification of the designated P/V parameter or the execution of the specified submodule, another PVMOD program control card is read. The program continues to execute the PVMOD submodule until it encounters an "END" control card. The data cards required by the various parts of the PVMOD module are described below.

7.3.1 Specifying P/V Parameters

Following the PVMOD program control card which selects a particular P/V parameter are one or more data cards. The nature of these cards depends on which P/V parameter is being specified.

P/V Parameter Data Cards (depends on which parameter)

DIMEN: Problem Dimensions

Columns 1- 5: NX = number of total system states
Columns 6-10: NX1 = number of noise-shaping states
Columns 11-15: NU = number of control system inputs
Columns 16-20: NW = number of random noise sources
Columns 21-25: NY = number of displayed outputs

A: The A matrix is specified as an NX x NX matrix as described in Section 5.

B: The B matrix is specified as an NX x NU matrix.

C: The C matrix is specified as an NY x NX matrix.

D: The D matrix is specified as an NY x NU matrix.

E: The E matrix is specified as an NX x NW matrix.

QY: Output weightings

The output weightings QY_i are specified as an NY vector as described in Section 5.

QX: State weightings

The state weightings QX_i are specified as an NX vector.

QU: Control weightings

The control weightings QU_i are specified as an NU vector.

QR: Control rate weightings and neuro-motor lag

The control rate weightings $Q\dot{R}_i$ along with the neuro-motor lag TN and a fractional tolerance TNTOL are specified as an (NU + 2) vector. If TN=0 or if NU > 1, TN and TNTOL are ignored, Tn is computed once using QR_i.

Otherwise, QR is taken as a first guess and is adjusted to yield the desired value of TN within the specified tolerance.

TD: Time delay
Columns 1-10: real number = TD.

WD: Random noise covariance
The variance of the random noise sources WD_i is specified as an NW vector.

TH: Thresholds
The observational thresholds TH_i are specified as an NY vector.

RS: Residual noise
The variance of the observational residual noise RS_i is specified as an NY vector.

PU: Motor noise ratio

Columns 1-10:	real number =	PU	motor noise ratio (dB)
Columns 11-20:	real number =	UTOL	motor noise tolerance (± dB)
Columns 21-30:	real number =	USTEP	motor noise iteration step factor (1.10 suggested)

VU: Motor noise
A first guess at the variance of the motor noise VU_i is specified as an NU vector.

PY: Observation noise ratio

Columns 1-10:	real number =	PY	observation noise ratio (dB)
Columns 11-20:	real number =	YTOL	observation noise tolerance (± dB)
Columns 21-30:	real number =	YSTEP	observation noise iteration step factor (1.10 suggested).

ATTN: Attention
The observation attention AT_i is specified as an NY vector.

VY: Observation noise
A first guess at the variance of the observation noise VY_i is specified as an NY vector.

FREQ: Frequencies for FDREP analysis (2 cards)
1st Card: Columns 1-5: Integer NFREQ
2nd Card: The frequencies in radians/sec are specified as an NFREQ vector.

7.3.2 VBINT Submodule

The purpose of the VBINT submodule is to specify sets of parameters regarding the interaction of the Biodynamic and the Pilot/Vehicle modules. The first card read by the VBINT submodule is an identifier card which determines which VBINT parameter is to be specified. See Section 3.2.4 for a description of the BDMOD/PVMOD interaction.

VBINT Parameter Identifier Card

Columns 1-5: Alphanumeric Identifier MCODE

Parameter Identifier MCODE

EPR : Specify parameters relating residual observation noise to EPR vibration

STICK: Specify the type of stick (force or displacement), the display channel associated with the stick (necessary for a displacement stick), and a first guess of the rms stick motion.

TD : Specify parameters relating the human's time delay to shoulder vibration and stick motion.

KVU : Specify parameters relating the human's motor noise to shoulder vibration and stick motion.

RESET: Turn off PVMOD/BDMOD interaction

ZZZZZ: End VBINT parameter specifications. Return to the PVMOD module.

Following the VBINT parameter identifier card are one or more parameter cards. The nature of these cards depends on which parameter is being specified.

VBINT Parameter Cards (depends on which parameter)

MCODE = EPR: NY data cards (one for each display card).
For each data card i = 1, NY
Columns 1- 5: Alphanumeric $LDISPL_i$
Columns 6-10: (blank)
Columns 11-20: Real number $KLAT_i$
Columns 21-30: Real number $KLONG_i$

LDISPL identifies the type of display

ACCEL: acceleration display
VELOC: velocity display
DISPL: displacement display

$KLAT_i$ and $KLONG_i$ are the EPR parameters (Eq. 10)

STICK:

Columns 1- 5: Alphanumeric IDSTK
Columns 6-10: (blank)
Columns 11-20: Integer NYSTK
Columns 21-30: Real number RMSSTK

IDSTK identifies the type of stick
FORCE: force stick
DISPL: displacement stick

NYSTK is the number of the display channel associated with the stick

RMSSTK is the first guess of the RMS stick displacement

TD:

Columns 1-10: Real number TD0
Columns 11-20: Real number K_τ
Columns 21-30: Real number TDTOL

TD0 is the static value for the time delay K_τ is the time delay vibration parameter (see Eq. 7) TDTOL is a fractional tolerance for computing the time delay

KVU:

Columns 1-10: Real number K_{vu}
Columns 11-20: Real number VUTOL
K_{vu} is the motor noise vibration parameter (see Eq. 13) VUTOL is a fractional tolerance for computing the motor noise

RESET: No data cards required

ZZZZZ: No data cards required

After the data cards are read, the program reads another parameter identifier card. The sequence is repeated until a ZZZZZ card is encountered.

7.3.3 PCOMP Submodule

The purpose of the PCOMP is to perform the Pilot/Vehicle computations and to print the results of these computations. The submodule operates automatically and requires just a single parameter card which contains two initialization flags.

PCOMP Parameter Card

Columns 1- 5: Integer INIT1

Columns 6-10: Integer INIT2

INIT1: If INIT1 $\neq$ 0, then all the observation noises are initialized to 1.0 and all the motor noises are initialized to 0.0. If INIT1 = 0, then the observation and motor noises retain their prior values.

INIT2: If INIT2 $\neq$ 1, then the PCOMP computations proceed normally, i.e. a set of iterative computations start from scratch. If INIT2 = 1, then the prior solution is used to initialize the computation, allowing an initializing procedure to be bypassed.

After the PCOMP computations are completed, and the results are printed, program control returns to the PVMOD module.

7.3.4 FDREP Submodule

The purpose of the FDREP submodule is to compute and print various frequency domain measures including describing functions, pilot remnant, and signal spectra. the FDREP submodule requires three parameter cards. The first card specifies the describing function, the second specifies the remnant, and the third spcifies the spectrum. Note that a single call to the FDREP submodule can generate at most one describing function, one remnant and one spectrum. Thus, if one wishes to calculate several describing functions, several remnants and/or several spectra, successive calls to the FDREP submodule are necessary. Note also that the frequencies employed in the FDREP computations are specified along with the other P/V parameters.

FDREP Parameter Card #1: Describing Function

Columns	1- 4:	(blank)
Column	5:	Alphanumeric LDFCN
Columns	6-10:	Integer MU
Columns	11-15:	Integer MY1
Columns	16-20:	Integer MY2
Columns	21-25:	Integer MW

LDFCN identifies the type of describing function to be computed. the integers MU, MY1, MY2, and MW identify respectively, the relevant control, first output, second output, and noise source for the describing function. A list of the various describing functions follows:

LDFCN = I: Internal describing function:
H(MU,MY1)

= E: Equivalent describing function:
E(MU, MY1) with respect to noise source W(MW)

= D: Display-Equivalent describing function:
D(MY1, MY2) with respect to noise source W(MW)

= C: Circulatory describing function:
Uses output Y(MY1) and its derivative Y(MY2)

= M: Multiple describing function:
H(MU,MY1) + S * H(MU,MY2)
= V: Vehicle Open-Loop describing function:
V(MY1,MU)
= 0 (Zero): Bypass describing function computations.

<u>FDREP Parameter Card #2: Remnant</u>

Columns 1- 4: (blank)
Columns 5: Alphanumeric LREMN
Columns 6-10: Integer MR

LREMN identifies the type of remnant (normalized or un-normalized) to be computed. The integer MV identifies the output upon which the remnant is reflected.

LREMN = N: Normalized remnant reflected on output Y(MR).
= U: Un-Normalized remnant reflected on output Y(MR).
= 0 (zero): Bypass remnant computations.

<u>FDREP Parameter Card #3: Spectrum</u>

Columns 1- 4: (blank)
Columns 5: Alphanumeric LSPEC
Columns 6-10: Integer MS

LSPEC identifier the class of signal and MS identifies the channel number of that signal for the spectrum computation.

A list of the various spectra follows:

LSPEC = X: Spectrum of state X(MS).
= Y: Spectrum of output Y(MS).
= U: Spectrum of control U(MS).
= 0 (zero): Bypass spectrum computations.

After the FDREP computations are completed, and the results are printed, program control returns to the PVMOD module.

8. SAMPLE PROBLEM

A sample problem illustrating many of the features of the PIVIB program is given in this section. A description of the problem is presented first, following by a listing of the input deck, and listing of the output.

8.1 DESCRIPTION OF THE SAMPLE PROBLEM

The sample problem corresponds fairly closely to the vibration environment and tracking task with the medium stiff and spring sticks described in Reference 11.

8.1.1 Biodynamic Parameters

The vibration environment is a Z-axis disturbance of about 0.26g rms consisting of a sum of five sinusoids. The vibration spectrum is shown in the following table:

Frequency (Hz)	Frequency (rad/sec)	Power (dB)
2	12.5	-17.7
3	21.0	-18.1
5	31.7	-19.2
7	43.8	-19.7
10	63.3	-20.1

The shoulder transfer function in the Z-axis is given by the equation:

$$SHXFR = \frac{1 + (B/K)S}{1 + (B/K)S + (M/K)S^2}$$

where K, B and M represent the spring constant, damping factor and mass, respectively, and where B/K = 0.033, and M/K = 0.0012.

The stick transfer function in the longitudinal axis is specified by the stick gain and the impedances ZT, ZO and ZS. The stick gain was set to unity, and ZT and ZO were determined empirically as given in the following table:

Frequency (rad/sec)	ZT Gain (dB)	ZT Phase (deg)	ZO Gain (dB)	ZO Phase (deg)
12.5	5.1	-72.	12.1	87.
21.0	4.7	-71.	10.6	97.
31.7	11.9	-114.	23.5	95.
43.8	14.0	-170.	28.3	91.
63.3	4.7	-223.	31.3	100.

The stick impedance ZS is given by the equation:

$$ZS(s) = \frac{M_S\, s^2}{386.4} + B_S\, s + K_S, \tag{19}$$

where K_S is the spring gradient (lbs/inch), B_S is the damping factor in lbs/(inch/sec), and M_S is the effective mass of the stick in pounds. These parameters are given in the following table for the stiff and sping sticks

	Stiff Stick	Spring Stick
K_S (lbs/inch)	130.0	7.0
B_S lbs/(inch/sec)	0.0103	0.027
M_S lbs	3.4	3.4

The Z-axis and Pitch-axis head transfer functions were determined empirically as given in the following table:

	Z-axis		Pitch-Axis	
Frequency (rad/sec)	Gain (dB)	Phase (deg)	Gain (dB)	Phase (deg)
12.5	-1.5	13.	11.5	-72.
21.0	-1.2	-3.	20.7	11.
31.7	-0.5	5.	28.0	-82.
43.8	3.4	-48.	27.8	-223.
63.3	1.2	-55.	26.2	-216.

The EPR transfer function is determined by the location of the stick and the distance to the display. The stick was located on the vibrating platform, and the display was about 30 inches in front of the pilot's head.

The display/stick transfer functions depend on the vehicle dynamics. The display quantities correspond to error, (error rate) /4=(EDOT4), and the stick input itself. For the dynamics under consideration these transfer functions turn out to be the following:

$$\begin{aligned} &\text{ERROR/STICK} = 4/s \\ &\text{EDOT4/STICK} = 1 \\ &\text{STICK/STICK} = 1 \end{aligned} \tag{20}$$

8.1.2 Pilot/Vehicle Parameters

The tracking dynamics are basically K/s. There is a first-order noise having a break frequency of 2 rad/sec applied

as a velocity disturbance. These dynamics also incorporate the following stick dynamics relating stick output C (in volts) to force input F (in lbs):

$$\frac{C}{F}(s) = \frac{K_C}{ZS} \tag{21}$$

where ZS, the stick impedance depends on the stick, and is given by Eq 19, and K_C the electrical stick gain is 117.0 volts/inch for the stiff stick, and 2.5 volts/inch for the spring stick. Consequently, the tracking dynamics depend on the stick.

If we define:

ERR = The tracking error
STK = The output of the stick
U = The (pilot's) input to the stick
W = The white noise disturbance
WF = The first-order (filtered) noise,

then the tracking dynamics are given by the following equations:

$$STK = \frac{13{,}300\ U}{s^2 + 1.17s + 14{,}770} \quad \text{(stiff stick)},$$

or (22)

$$STK = \frac{284.1\ U}{s^2 + 3.068s + 795.5} \quad \text{(spring stick)};$$

$$W_F = \frac{2W}{s + 2}, \tag{23}$$

and

$$ERR = \frac{4\ STK + 2\ W_F}{s} \tag{24}$$

The system outputs are:

$$Y_1 = ERR \tag{25}$$

$$Y_2 = \frac{ERR}{4} = STK + W_F/2 \tag{26}$$

$$Y_3 = STK \tag{27}$$

$$Y_4 = U \tag{28}$$

In state-variable form the tracking dynamics are given by:

$$\underline{X} = \underline{A}\ \underline{X} + \underline{B}U + \underline{E}W, \tag{29}$$

where the states are:

$X_1 = W_F$

$X_2 = ERR$

$X_3 = STK$

$X_4 = \dot{STK}$,

and the outputs are given by:

$$\underline{Y} = \underline{C}\ \underline{X} + \underline{D}\ \underline{U} \tag{30}$$

The matrices in Equations 29 and 30 are thus:

$$\underline{A} = \begin{bmatrix} 2 & 0 & 0 & 0 \\ 2 & 0 & 4 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -14,770 & -1.17 \end{bmatrix} \quad \text{(stiff stick)}$$

$$A = \begin{bmatrix} -2 & 0 & 0 & 0 \\ 2 & 0 & 4 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -795.5 & -3.068 \end{bmatrix} \text{ (spring stick)}$$

$$B = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 13{,}330 \end{bmatrix} \qquad B = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 284.1 \end{bmatrix} \qquad E = \begin{bmatrix} 2 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

(stiff stick) (spring stick)

$$C = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0.5 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \qquad D = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

The *non-zero* terms of the cost functional (see Eq 14) were selected as follows: 1) The cost on error, QY_1, was arbitrarily set to unity. 2) The cost on control, QU, was set to 0.03, reflecting the fact that the test subjects were found to consider the presence of a 1-inch tracking error as "costly" as the requirement to generate about 30 pounds of control force. (See Ref. 11). 3) The cost on control rate, QR, was initially set to 0.001, but was adjusted (by the program) to yield the value $\tau_N = 0.1$ with a tolerance of 10%.

The covariance of the driving noise was 0.34, and the observational thresholds (see Eqs 8 and 9) were:

$$TH = \begin{bmatrix} 0.135 \\ 0.54 \\ 0.54 \\ 0 \end{bmatrix}$$

The base observation noise/signal ratio PY was -21dB, with a tolerance of 0.1dB and an iteration step factor of 1.1. The attention vector was given by

$$AT = \begin{bmatrix} 1 \\ 1 \\ 0.001 \\ 0.001 \end{bmatrix}$$

reflecting the fact that full attention was given to monitoring error and error rate, and that virtually no attention was given to the stick or the stick rate. The latter two quantities were included in the display vector merely to allow variance scores to be computed for them. The following initial guess of the observation noises was made:

$$VY = \begin{bmatrix} 0.02 \\ 0.02 \\ 1.0 \\ 1.0 \end{bmatrix}$$

The vibration interface VBINT parameters were chosen as follows. The stiff stick was identified as a FORCE stick, while the spring stick was identified as a displacement DISPL stick; the 3rd display channel was associated with the stick; and the first guess of the RMS stick motion was 0.32. The

static time delay was set to 0.15 sec, the time delay vibration parameter K_τ was 0.06, and the time delay tolerance was 10%. The motor noise vibration parameter K_{vu} was 0.012, and the motor noise tolerance was 10%.

Because the motor noise was to be computed by the VBINT submodule, the motor noise ratio was set arbitrarily to -24 dB with a tolerance of 300dB, and an iteration step factor of 0.0 so that no iteration would occur.

After, the PCOMP module was called, three describing functions were obtained, along with a normalized remnant and the spectrum of the control. The nine frequencies for this analysis went from 0.5 rad/sec up to 10.6 rad/sec.

Regarding the portion of the input deck for the second part of the sample problem dealing with the spring stick, notice that in the BDMOD when the new stick impedance is specified, the previously computed stick transfer function is nulled. This is done to force the program to compute the new stick transfer function. (See Section 4.2.5.1).

In addition, notice that in the PVMOD, the VBINT submodule is called a second time. This is done because the VBINT parameters are not restored after a call to the BDMOD module. (See Section 9.2).

8.2 INPUT DECK FOR THE SAMPLE PROBLEM

```
MSTF & MSPR (CENTER) ... TEST #5
BDMOD
FIRST BIODYNAMIC MODULE TEST ... MSTF
FREQS
CONT
       200.0        6.0         2
DISCR    5
        12.5       21.0       31.7       43.8       63.3
ZZZZZ
VIBR
DISCR           1    1
GNPH     5
           1          2          3          4          5
       -17.7      -18.1      -19.2      -19.7      -20.1
         0.0        0.0        0.0        0.0        0.0
IDENT           1
Z
ZZZZZ
BIOTR
SHOUL           3    1
POLYS    1      2
         1.0    0.033
         1.0    0.033     0.0012
STICKZT         1    1
GNPH     5
        12.5       21.0       31.7       43.8       63.3
         5.1        4.7       11.9       14.0        4.7
       -72.0      -71.0     -114.0     -170.0     -223.0
STICKZO         1    1
GNPH     5
        12.5       21.0       31.7       43.8       63.3
        12.1       10.6       23.5       28.3       31.3
        87.0       97.0       95.0       91.0      100.0
STICKZS         1    1
POLYS    2      0
       130.0    0.0103    0.00181
         1.0
STICKGAIN       1
         1.0
STICKIDENT      1
LONG
HEAD            2    1
GNPH     5
        12.5       21.0       31.7       43.8       63.3
        -1.5       -1.2       -0.5        3.4        1.2
        13.0       -3.0        5.0      -48.0      -55.0
HEAD            3    1
GNPH     5
        12.5       21.0       31.7       43.8       63.3
        11.5       20.7       28.0       27.8       26.2
       -72.0       11.0      -82.0     -223.0     -216.0
EYEPT
ON                 30.0
DISPL           1    1
```

Input Deck (Continued)

```
POLYS    0    1
     4.0
     0.0       1.0
DISPLIDENT    1
ERROR
DISPL         2    1
POLYS    0    0
       1.0
       1.0
DISPLIDENT    2
EDOT4
DISPL         3    1
POLYS    0    0
       1.0
       1.0
DISPLIDENT    3
STICK
ZZZZZ
BCOMP
END
PVMOD
FIRST PILOT/VEHICLE MODULE TEST ... MSTF
DIMEN
    4      1     1     1     4
A
      -2.0       0.0          0.0         0.0
       2.0       0.0          4.0         0.0
       0.0       0.0          0.0         1.0
       0.0       0.0   -1.477E+4        -1.17
B
       0.0
       0.0
       0.0
  1.33E+4
E
       2.0
       0.0
       0.0
       0.0
C
       0.0       1.0          0.0         0.0
       0.5       0.0          1.0         0.0
       0.0       0.0          1.0         0.0
       0.0       0.0          0.0         0.0
D
       0.0
       0.0
       0.0
       1.0
QY
       1.0       0.0          0.0         0.0
QU
      0.03
QR
    1.0E-3       0.1          0.1
```

Input Deck (Continued)

```
WD
      0.34
TH
     0.135       0.54       0.54       0.0
VBINT
STICK
FORCE               3       0.32
TD
      0.15       0.06        0.1
KVU
     0.012        0.1
ZZZZZ
PU
     -24.0      300.0        0.0
VY
      0.02       0.02        1.0        1.0
PY
     -21.0        0.1        1.1
ATTN
       1.0        1.0    1.0E-03    1.0E-03
PCOMP
    0    0
FREQ
    9
       0.5        0.8        1.2        1.9        3.0        4.3        6.3        8.2
      10.6
FDREP
    E    1    1    0    1
    N    1
    U    1
FDREP
    D    0    3    1    1
    0
    0
FDREP
    D    0    4    1    1
    0
    0
END
BDMOD
SECOND BIODYNAMIC MODULE TEST ... MSPR
BIOTR
STICK               1    1
NULL
STICKZS             1    1
POLYS         2     0
       7.0      0.027    0.00181
       1.0
ZZZZZ
BCOMP
END
PVMOD
SECOND PILOT/VEHICLE MODULE TEST ... MSPR
DIMEN
    4    1    1    1    4
```

Input Deck (Continued)

```
A
        -2.0           0.0          0.0          0.0
         2.0           0.0          4.0          0.0
         0.0           0.0          0.0          1.0
         0.0           0.0  -7.955E+2       -3.068
B
         0.0
         0.0
         0.0
    2.841E+2
E
         2.0
         0.0
         0.0
         0.0
C
         0.0           1.0          0.0          0.0
         0.5           0.0          1.0          0.0
         0.0           0.0          1.0          0.0
         0.0           0.0          0.0          0.0
D
         0.0
         0.0
         0.0
         1.0
QR
      1.0E-3           0.1          0.1
VBINT
STICK
DISPL                    3         0.32
TD
        0.15          0.06          0.1
KVU
       0.012           0.1
ZZZZZ
PCOMP
    0    0
FDREP
    E    1    1    0    1
    N    1
    U    1
FDREP
    D    0    3    1    1
    0
    0
FDREP
    D    0    4    1    1
    0
    0
END
EXIT
```

8.3 PROGRAM OUTPUT FOR THE SAMPLE PROBLEM

```
STARTING VEXEC
 29 JUL 76   20.53.27
MSTF & MSPR (CENTER) ... TEST #5

ENTERING BDMOD

FIRST BIODYNAMIC MODULE TEST ... MSTF

VIBR  TRANSFER FUNCTION    CHANNEL NO. 1  Z
                      SOURCE 1
                    1ST   INPUT
                     GAIN PHASE
DFREQ RAD/SEC
     12.500        -17.7      0
     21.000        -18.1      0
     31.700        -19.2      0
     43.800        -19.7      0
     63.300        -20.1      0

SHOUL TRANSFER FUNCTION    CHANNEL NO. 3  Z
                      SOURCE 1
                    Z      VIBR
                     GAIN PHASE
DFREQ RAD/SEC
     12.500          1.5     -5
     21.000          3.2    -21
     31.700          2.7    -55
     43.800          -.9    -77
     63.300         -5.5    -87

STICK TRANSFER FUNCTION    CHANNEL NO. 1  LONG
                      SOURCE 1
                    Z      VIBR
                     GAIN PHASE
DFREQ RAD/SEC
     12.500        -37.2    -74
     21.000        -37.5    -73
     31.700        -30.2   -121
     43.800        -28.2   -182
     63.300        -37.0   -241

HEAD  TRANSFER FUNCTION    CHANNEL NO. 2  Z
                      SOURCE 1
                    Z      VIBR
                     GAIN PHASE
DFREQ RAD/SEC
     12.500         -1.5     13
     21.000         -1.2     -3
     31.700          -.5      5
     43.800          3.4    -48
     63.300          1.2    -55

HEAD  TRANSFER FUNCTION    CHANNEL NO. 3  PITCH
                      SOURCE 1
                    Z      VIBR
                     GAIN PHASE
```

Program Output (Continued)

```
DFREQ RAD/SEC
    12.500          11.5    -72
    21.000          20.7     11
    31.700          28.0    -82
    43.800          27.8   -223
    63.300          26.2   -216

DISPL TRANSFER FUNCTION   CHANNEL NO. 1  ERROR
                   SOURCE 1
                 LONG  STICK
                  GAIN PHASE
DFREQ RAD/SEC
    12.500          -9.9    -90
    21.000         -14.4    -90
    31.700         -18.0    -90
    43.800         -20.8    -90
    63.300         -24.0    -90

DISPL TRANSFER FUNCTION   CHANNEL NO. 2  EDOT4
                   SOURCE 1
                 LONG  STICK
                  GAIN PHASE
DFREQ RAD/SEC
    12.500           0.       0
    21.000           0.       0
    31.700           0.       0
    43.800           0.       0
    63.300           0.       0

DISPL TRANSFER FUNCTION   CHANNEL NO. 3  STICK
                   SOURCE 1
                 LONG  STICK
                  GAIN PHASE
DFREQ RAD/SEC
    12.500           0.       0
    21.000           0.       0
    31.700           0.       0
    43.800           0.       0
    63.300           0.       0


EYEPT TRANSFER FUNCTION   CHANNEL NO. 2  LONG
                   SOURCE 1
                 Z     VIBR
                  GAIN PHASE
DFREQ RAD/SEC
    12.500          33.8     44
    21.000          48.7   -171
    31.700          57.1     97
    43.800          54.8     -8
    63.300          56.0      0


VIBR  POWER SPECTRUM
              CHAN  1
               Z
```

Program Output (Continued)

```
DFREQ RAD/SEC
    12.500      -17.7
    21.000      -18.1
    31.700      -19.2
    43.800      -19.7
    63.300      -20.1

RMS ACCELERATION   VIBR  CHAN  1  Z      =   2.549E-01

SHOUL POWER SPECTRUM
                CHAN  3
                  Z
DFREQ RAD/SEC
    12.500      -16.2
    21.000      -14.9
    31.700      -16.5
    43.800      -20.6
    63.300      -25.6

RMS ACCELERATION   SHOUL CHAN  3  Z      =   3.005E-01

STICK POWER SPECTRUM
                CHAN  1
                  LONG
DFREQ RAD/SEC
    12.500      -54.9
    21.000      -55.6
    31.700      -49.4
    43.800      -47.9
    63.300      -57.1

RMS                STICK CHAN  1  LONG   =   5.964E-03

HEAD  POWER SPECTRUM
                CHAN  2     CHAN  3
                  Z          PITCH
DFREQ RAD/SEC
    12.500      -19.2        -6.2
    21.000      -19.3         2.6
    31.700      -19.7         8.8
    43.800      -16.3         8.1
    63.300      -18.9         6.1

RMS ACCELERATION   HEAD  CHAN  2  Z      =   2.661E-01
RMS ACCELERATION   HEAD  CHAN  3  PITCH  =   4.492E+00

DISPL POWER SPECTRUM
                CHAN  1     CHAN  2     CHAN  3
                 ERROR       EDOT4       STICK
DFREQ RAD/SEC
    12.500      -64.8       -54.9       -54.9
    21.000      -70.0       -55.6       -55.6
    31.700      -67.4       -49.4       -49.4
    43.800      -68.7       -47.9       -47.9
    63.300      -81.1       -57.1       -57.1
```

Program Output (Continued)

```
RMS DISPLACEMENT   DISPL CHAN  1  ERROR =   8.703E-04
RMS DISPLACEMENT   DISPL CHAN  2  EDOT4 =   5.964E-03
RMS DISPLACEMENT   DISPL CHAN  3  STICK =   5.964E-03

EYEPT POWER SPECTRUM
           CHAN  2
            LONG
DFREQ RAD/SEC
    12.500      16.1
    21.000      30.6
    31.700      37.9
    43.800      35.1
    63.300      35.9

RMS ACCELERATION   EYEPT CHAN  2  LONG  =   1.153E+02
RMS VELOCITY       EYEPT CHAN  2  LONG  =   2.971E+00
RMS DISPLACEMENT   EYEPT CHAN  2  LONG  =   8.527E-02


LEAVING BDMOD

ENTERING PVMOD

FIRST PILOT/VEHICLE MODULE TEST ... MSTF

RICCATI SOLN IN  6 ITERATIONS
RICCATI SOLN IN  7 ITERATIONS
RICCATI SOLN IN  5 ITERATIONS
VY( 1)= -18.00    2.00E-02
VY( 2)= -26.07    2.00E-02
VY( 3)=  -9.08    1.00E+00
VY( 4)=    .85    1.00E+00
VU( 1)= -18.94    1.13E-02
RICCATI SOLN IN  4 ITERATIONS
VY( 1)= -21.45    9.03E-03
VY( 2)= -20.71    6.88E-02
VY( 3)=   9.41    7.06E+01
VY( 4)=   9.27    7.09E+00
VU( 1)= -19.05    1.13E-02
RICCATI SOLN IN  3 ITERATIONS
VY( 1)= -21.02    1.01E-02
VY( 2)= -21.03    6.39E-02
VY( 3)=   8.96    6.37E+01
VY( 4)=   8.97    6.62E+00
VU( 1)= -19.06    1.13E-02
RICCATI SOLN IN  4 ITERATIONS
VY( 1)= -20.56    1.02E-02
VY( 2)= -20.91    6.44E-02
VY( 3)=   9.08    6.44E+01
VY( 4)=   9.64    6.68E+00
VU( 1)= -20.82    6.97E-03
RICCATI SOLN IN  2 ITERATIONS
VY( 1)= -20.96    9.09E-03
VY( 2)= -21.01    6.30E-02
VY( 3)=   8.99    6.30E+01
```

Program Output (Continued)

```
VY( 4)=    8.95      5.67E+00
VU( 1)= -20.80       6.97E-03
NO. OF TOTAL SYSTEM STATES    4
NO. OF NOISE SHAPING STATES   1
NO. OF CONTROL SYSTEM INPUTS  1
NO. OF RANDOM NOISE SOURCES   1
NO. OF DISPLAYED OUTPUTS      4

 A          MATRIX
  -2.000E+00     0.             0.            0.
   2.000E+00     0.             4.000E+00     0.
   0.            0.             0.            1.000E+00
   0.            0.            -1.477E+04    -1.170E+00

 B          MATRIX
   0.
   0.
   0.
   1.330E+04

 C          MATRIX
   0.            1.000E+00      0.            0.
   5.000E-01     0.             1.000E+00     0.
   0.            0.             1.000E+00     0.
   0.            0.             0.            0.

 D          MATRIX
   0.
   0.
   0.
   1.000E+00

 E          MATRIX
   2.000E+00
   0.
   0.
   0.

QY          VECTOR
   1.000E+00     0.             0.            0.

QX          VECTOR
   0.            0.             0.            0.

QU          VECTOR
   3.000E-02

QR          VECTOR
   4.442E-03

TN IN  2 ITERATIONS

TN          MATRIX
   9.245E-02

HUMAN*S T.D. =    .188

WD          VECTOR
   3.400E-01
```

Program Output (Continued)

```
TH          VECTOR
    1.350E-01     5.400E-01     5.400E-01     0.

RS          VECTOR
    0.            0.            0.            0.

VU          VECTOR
    7.518E-03

BASE OBS NOISE RATIO=-21.00

AT          VECTOR
    1.000E+00     1.000E+00     1.000E-03     1.000E-03
NOISES IN  2 ITERATIONS

    RATIOS(DB)   ABSOLUTE
PU( 1)= -20.47    7.52E-03
PY( 1)= -20.96    9.09E-03
PY( 2)= -21.01    6.30E-02
PY( 3)=   8.99    6.30E+01
PY( 4)=   8.95    5.67E+00

       VARIANCE       RMS            COST
X( 1)= 3.400E-01     5.831E-01
X( 2)= 2.141E-01     4.628E-01
X( 3)= 4.724E-01     6.873E-01
X( 4)= 4.222E+03     6.497E+01
U( 1)= 2.300E-01     4.796E-01     6.900E-03
R( 1)= 1.314E+01     3.625E+00     5.839E-02
Y( 1)= 2.141E-01     4.628E-01     2.141E-01
Y( 2)= 4.746E-01     6.889E-01
Y( 3)= 4.724E-01     6.873E-01
Y( 4)= 2.300E-01     4.796E-01

J(U)= 2.794E-01

              ESTIMATE                    EST. ERROR          FRACT. ERR.
       VARIANCE      RMS           VARIANCE      RMS
X( 1)= 5.603E-02     2.367E-01     2.840E-01     5.329E-01     8.352E-01
X( 2)= 9.334E-02     3.055E-01     1.208E-01     3.476E-01     5.641E-01
X( 3)= 2.729E-01     5.224E-01     1.995E-01     4.467E-01     4.224E-01
X( 4)= 1.733E+03     4.163E+01     2.488E+03     4.988E+01     5.894E-01
X( 5)= 1.923E-01     4.385E-01     3.770E-02     1.942E-01     1.639E-01
Y( 1)= 9.334E-02     3.055E-01     1.208E-01     3.476E-01     5.641E-01
Y( 2)= 2.053E-01     4.531E-01     2.694E-01     5.190E-01     5.675E-01
Y( 3)= 2.729E-01     5.224E-01     1.995E-01     4.467E-01     4.224E-01
Y( 4)= 1.923E-01     4.385E-01     3.770E-02     1.942E-01     1.639E-01

VIBRATION INTERFACE OUTPUTS...

EPR COEFFICIENTS
OUTPUT      MODE       LAT-AXIS      LONG-AXIS
    1                  0.            0.
    2                  0.            0.
    3                  0.            0.
    4                  0.            0.
```

Program Output (Continued)

```
STICK TYPE  FORCE
HUMAN*S STATIC T.D. =    .150
T.D. VIBR. FACTOR, KT =  6.000E-02
MOTOR NOISE VIBR. FACTOR, KVU =  1.200E-02
VIBINT IN  3 ITERATIONS

VIBRATION FEEDTHROUGH INCREMENTED SCORES
        VARIANCE          RMS
Y( 1)= 2.141E-01      4.628E-01
Y( 2)= 4.747E-01      6.890E-01
Y( 3)= 4.724E-01      6.873E-01
STICK
Y( 3)= 4.724E-01      6.873E-01


EQUIVALENT DFCN  E( 1, 1) WRTC W( 1)
NORMALIZED REMNANT REFLECTED ON Y( 1)
SPECTRUM OF SIGNAL U( 1)
```

FREQ	MAG	PHASE	REMN	TOTAL	UNCOR	1CORR	UNCR/CR
.50	-.9	-9	-14.5	-14.9	-38.2	-14.9	-23.3
.80	-1.0	-15	-14.5	-15.1	-34.0	-15.1	-18.9
1.20	-1.2	-21	-14.5	-15.4	-30.2	-15.5	-14.7
1.90	-1.6	-31	-14.6	-15.9	-25.6	-16.4	-9.3
3.00	-2.0	-44	-14.7	-16.2	-21.1	-18.0	-3.1
4.30	-1.9	-59	-15.1	-16.4	-18.5	-20.5	2.0
6.30	-1.4	-85	-15.9	-17.5	-18.2	-25.6	7.4
8.20	-.5	-113	-16.8	-19.8	-20.1	-31.1	11.0
10.60	.2	-156	-17.6	-23.2	-23.3	-37.8	14.5

DISPLAY EQUIV DFCN D(3, 1) WRTO W(1)

FREQ	MAG	PHASE
.50	-1.8	-9
.80	-1.9	-15
1.20	-2.2	-21
1.90	-2.5	-31
3.00	-2.9	-44
4.30	-2.8	-59
6.30	-2.2	-85
8.20	-1.4	-113
10.60	-.6	-156

DISPLAY EQUIV DFCN D(4, 1) WRTO W(1)

FREQ	MAG	PHASE
.50	-.9	-9
.80	-1.0	-15
1.20	-1.2	-21
1.90	-1.6	-31
3.00	-2.0	-44
4.30	-1.9	-59
6.30	-1.4	-85
8.20	-.5	-113
10.60	.2	-156

LEAVING PVMOD

Program Output (Continued)

ENTERING BDMOD

SECOND BIODYNAMIC MODULE TEST ... MSPR

VIBR TRANSFER FUNCTION CHANNEL NO. 1 Z

	SOURCE 1	
	1ST	INPUT
DFREQ RAD/SEC	GAIN	PHASE
12.500	-17.7	0
21.000	-18.1	0
31.700	-19.2	0
43.800	-19.7	0
63.300	-20.1	0

SHOUL TRANSFER FUNCTION CHANNEL NO. 3 Z

	SOURCE 1	
	Z	VIBR
DFREQ RAD/SEC	GAIN	PHASE
12.500	1.5	-5
21.000	3.2	-21
31.700	2.7	-55
43.800	-.9	-77
63.300	-5.5	-87

STICK TRANSFER FUNCTION CHANNEL NO. 1 LONG

	SOURCE 1	
	Z	VIBR
DFREQ RAD/SEC	GAIN	PHASE
12.500	-13.2	-104
21.000	-12.2	-105
31.700	-12.3	-190
43.800	-14.7	-254
63.300	-27.0	-323

HEAD TRANSFER FUNCTION CHANNEL NO. 2 Z

	SOURCE 1	
	Z	VIBR
DFREQ RAD/SEC	GAIN	PHASE
12.500	-1.5	13
21.000	-1.2	-3
31.700	-.5	5
43.800	3.4	-48
63.300	1.2	-55

HEAD TRANSFER FUNCTION CHANNEL NO. 3 PITCH

	SOURCE 1	
	Z	VIBR
DFREQ RAD/SEC	GAIN	PHASE
12.500	11.5	-72
21.000	20.7	11
31.700	28.0	-82
43.800	27.8	-223
63.300	26.2	-216

Program Output (Continued)

```
DISPL TRANSFER FUNCTION    CHANNEL NO. 1  ERROR
                    SOURCE 1
                  LONG  STICK
                   GAIN PHASE
DFREQ RAD/SEC
    12.500         -9.9   -90
    21.000        -14.4   -90
    31.700        -18.0   -90
    43.800        -20.8   -90
    63.300        -24.0   -90

DISPL TRANSFER FUNCTION    CHANNEL NO. 2  EDOT4
                    SOURCE 1
                  LONG  STICK
                   GAIN PHASE
DFREQ RAD/SEC
    12.500         0.       0
    21.000         0.       0
    31.700         0.       0
    43.800         0.       0
    63.300         0.       0

DISPL TRANSFER FUNCTION    CHANNEL NO. 3  STICK
                    SOURCE 1
                  LONG  STICK
                   GAIN PHASE
DFREQ RAD/SEC
    12.500         0.       0
    21.000         0.       0
    31.700         0.       0
    43.800         0.       0
    63.300         0.       0

EYEPT TRANSFER FUNCTION    CHANNEL NO. 2  LONG
                    SOURCE 1
                   Z    VIBR
                   GAIN PHASE
DFREQ RAD/SEC
    12.500         33.8    44
    21.000         48.7  -171
    31.700         57.1    97
    43.800         54.8    -8
    63.300         56.0     0

VIBR  POWER SPECTRUM
                 CHAN   1
                   Z
DFREQ RAD/SEC
    12.500        -17.7
    21.000        -18.1
    31.700        -19.2
    43.800        -19.7
    63.300        -20.1
```

Program Output (Continued)

```
RMS ACCELERATION    VIBR  CHAN  1  Z      =   2.549E-01

SHOUL POWER SPECTRUM
                 CHAN  3
                  Z
DFREQ RAD/SEC
    12.500       -16.2
    21.000       -14.9
    31.700       -16.5
    43.800       -20.6
    63.300       -25.6

RMS ACCELERATION    SHOUL CHAN  3  Z      =   3.005E-01

STICK POWER SPECTRUM
                 CHAN  1
                  LONG
DFREQ RAD/SEC
    12.500       -30.9
    21.000       -30.3
    31.700       -31.5
    43.800       -34.4
    63.300       -47.1

RMS                 STICK CHAN  1  LONG   =   5.329E-02

HEAD  POWER SPECTRUM
                 CHAN  2      CHAN  3
                  Z             PITCH
DFREQ RAD/SEC
    12.500       -19.2          -6.2
    21.000       -19.3           2.6
    31.700       -19.7           8.8
    43.800       -16.3           8.1
    63.300       -18.9           6.1

RMS ACCELERATION    HEAD  CHAN  2  Z      =   2.661E-01
RMS ACCELERATION    HEAD  CHAN  3  PITCH  =   4.492E+00

DISPL POWER SPECTRUM
                 CHAN  1      CHAN  2      CHAN  3
                  ERROR        EDOT4        STICK
DFREQ RAD/SEC
    12.500       -40.8        -30.9        -30.9
    21.000       -44.7        -30.3        -30.3
    31.700       -49.5        -31.5        -31.5
    43.800       -55.2        -34.4        -34.4
    63.300       -71.1        -47.1        -47.1

RMS DISPLACEMENT    DISPL CHAN  1  ERROR  =   1.150E-02
RMS DISPLACEMENT    DISPL CHAN  2  EDOT4  =   5.329E-02
RMS DISPLACEMENT    DISPL CHAN  3  STICK  =   5.329E-02
```

Program Output (Continued)

```
EYEPT POWER SPECTRUM
                   CHAN  2
                    LONG
DFREQ RAD/SEC
     12.500        16.1
     21.000        30.6
     31.700        37.9
     43.800        35.1
     63.300        35.9

RMS ACCELERATION    EYEPT CHAN  2  LONG  =   1.153E+02
RMS VELOCITY        EYEPT CHAN  2  LONG  =   2.971E+00
RMS DISPLACEMENT    EYEPT CHAN  2  LONG  =   8.527E-02


LEAVING BDMOD

ENTERING PVMOD

SECOND PILOT/VEHICLE MODULE TEST ... MSPR

RICCATI SOLN IN  5 ITERATIONS
RICCATI SOLN IN  4 ITERATIONS
RICCATI SOLN IN  4 ITERATIONS
VY( 1)= -21.38    9.09E-03
VY( 2)= -23.34    6.30E-02
VY( 3)=   6.24    6.30E+01
VY( 4)=   2.57    5.67E+00
VU( 1)= -25.32    1.13E-02
RICCATI SOLN IN  2 ITERATIONS
VY( 1)= -21.14    9.99E-03
VY( 2)= -20.74    1.12E-01
VY( 3)=   9.23    1.25E+02
VY( 4)=   9.28    2.68E+01
VU( 1)= -25.38    1.13E-02
RICCATI SOLN IN  2 ITERATIONS
VY( 1)= -21.00    1.03E-02
VY( 2)= -21.02    1.05E-01
VY( 3)=   8.98    1.17E+02
VY( 4)=   8.97    2.50E+01
VU( 1)= -25.38    1.13E-02
RICCATI SOLN IN  3 ITERATIONS
VY( 1)= -20.86    1.04E-02
VY( 2)= -21.26    1.06E-01
VY( 3)=   8.73    1.18E+02
VY( 4)=   9.11    2.52E+01
VU( 1)= -26.41    8.77E-03
RICCATI SOLN IN  2 ITERATIONS
VY( 1)= -21.00    9.98E-03
VY( 2)= -20.98    1.13E-01
VY( 3)=   9.02    1.26E+02
VY( 4)=   8.99    2.45E+01
VU( 1)= -26.40    8.77E-03
NO. OF TOTAL SYSTEM STATES    4
NO. OF NOISE SHAPING STATES   1
NO. OF CONTROL SYSTEM INPUTS  1
NO. OF RANDOM NOISE SOURCES   1
```

Program Output (Continued)

```
NO. OF DISPLAYED OUTPUTS      4

A          MATRIX
 -2.000E+00   0.          0.          0.
  2.000E+00   0.          4.000E+00   0.
  0.          0.          0.          1.000E+00
  0.          0.         -7.955E+02  -3.068E+00

B          MATRIX
  0.
  0.
  0.
  2.841E+02

C          MATRIX
  0.          1.000E+00   0.          0.
  5.000E-01   0.          1.000E+00   0.
  0.          0.          1.000E+00   0.
  0.          0.          0.          0.

D          MATRIX
  0.
  0.
  0.
  1.000E+00

E          MATRIX
  2.000E+00
  0.
  0.
  0.

QY         VECTOR
  1.000E+00   0.          0.          0.

QX         VECTOR
  0.          0.          0.          0.

QU         VECTOR
  3.000E-02

QR         VECTOR
  1.532E-03

TN IN  2 ITERATIONS

TN         MATRIX
  9.982E-02

HUMAN*S T.D. =   .195

WD         VECTOR
  3.400E-01

TH         VECTOR
  1.350E-01   5.400E-01   5.400E-01   0.

RS         VECTOR
  0.          0.          0.          0.
```

Program Output (Continued)

```
VU          VECTOR
    8.971E-03

BASE OBS NOISE RATIO=-21.00

AT          VECTOR
    1.000E+00    1.000E+00    1.000E-03    1.000E-03
NOISES IN  2 ITERATIONS

     RATIOS(DB)    ABSOLUTE
PU( 1)= -26.31     8.97E-03
PY( 1)= -21.00     9.98E-03
PY( 2)= -20.98     1.13E-01
PY( 3)=   9.02     1.26E+02
PY( 4)=   8.99     2.45E+01

        VARIANCE       RMS          COST
X( 1)= 3.400E-01    5.831E-01
X( 2)= 2.467E-01    4.967E-01
X( 3)= 1.615E-01    4.019E-01
X( 4)= 2.611E+01    5.110E+00
U( 1)= 9.840E-01    9.920E-01    2.952E-02
R( 1)= 3.247E+01    5.699E+00    4.977E-02
Y( 1)= 2.467E-01    4.967E-01    2.467E-01
Y( 2)= 1.755E-01    4.189E-01
Y( 3)= 1.615E-01    4.019E-01
Y( 4)= 9.840E-01    9.920E-01

J(U)= 3.260E-01

             ESTIMATE                          EST. ERROR          FRACT. ERR.
        VARIANCE       RMS          VARIANCE       RMS
X( 1)= 5.357E-02    2.315E-01    2.864E-01    5.352E-01    8.424E-01
X( 2)= 1.232E-01    3.510E-01    1.235E-01    3.514E-01    5.006E-01
X( 3)= 1.413E-01    3.759E-01    2.026E-02    1.423E-01    1.254E-01
X( 4)= 1.380E+01    3.715E+00    1.231E+01    3.508E+00    4.714E-01
X( 5)= 9.401E-01    9.696E-01    4.392E-02    2.096E-01    4.464E-02
Y( 1)= 1.232E-01    3.510E-01    1.235E-01    3.514E-01    5.006E-01
Y( 2)= 8.387E-02    2.896E-01    9.158E-02    3.026E-01    5.220E-01
Y( 3)= 1.413E-01    3.759E-01    2.026E-02    1.423E-01    1.254E-01
Y( 4)= 9.401E-01    9.696E-01    4.392E-02    2.096E-01    4.464E-02

VIBRATION INTERFACE OUTPUTS...

EPR COEFFICIENTS
 OUTPUT      MODE       LAT-AXIS     LONG-AXIS
     1                  0.           0.
     2                  0.           0.
     3                  0.           0.
     4                  0.           0.

STICK TYPE  DISPL
STICK IS OUTPUT NO.  3
HUMAN*S STATIC T.D. =    .150
T.D. VIBR. FACTOR, KT =  6.000E-02
MOTOR NOISE VIBR. FACTOR, KVU =  1.200E-02
VIBINT IN  3 ITERATIONS
```

Program Output (Continued)

```
VIBRATION FEEDTHROUGH INCREMENTED SCORES
          VARIANCE          RMS
Y( 1)= 2.469E-01     4.969E-01
Y( 2)= 1.783E-01     4.223E-01
Y( 3)= 1.644E-01     4.054E-01
STICK
Y( 3)= 1.644E-01     4.054E-01

EQUIVALENT DFCN  E( 1, 1) WRTO W( 1)
NORMALIZED REMNANT REFLECTED ON Y( 1)
SPECTRUM OF SIGNAL U( 1)

  FREQ       MAG  PHASE     REMN    TOTAL   UNCOR    1CORR  UNCR/CR
   .50       5.3    -10    -16.7     -6.9   -31.8     -6.9    -24.9
   .80       5.2    -15    -16.8     -7.0   -27.6     -7.1    -20.5
  1.20       5.0    -22    -16.9     -7.4   -23.8     -7.4    -16.4
  1.90       4.8    -33    -17.0     -8.0   -19.4     -8.3    -11.1
  3.00       4.6    -48    -17.3     -8.9   -15.2    -10.1     -5.1
  4.30       4.7    -67    -17.6    -10.2   -13.1    -13.2       .1
  6.30       5.4    -99    -18.1    -12.9   -13.9    -19.7      5.9
  8.20       6.1   -134    -18.4    -15.9   -16.3    -26.2      9.9
 10.60       5.9   -186    -18.6    -19.4   -19.6    -33.7     14.1

DISPLAY EQUIV DFCN  D( 3, 1) WRTO W( 1)

  FREQ       MAG  PHASE
   .50      -3.6    -10
   .80      -3.7    -15
  1.20      -3.9    -22
  1.90      -4.1    -33
  3.00      -4.3    -49
  4.30      -4.0    -68
  6.30      -3.1   -100
  8.20      -2.1   -136
 10.60      -1.7   -189

DISPLAY EQUIV DFCN  D( 4, 1) WRTO W( 1)

  FREQ       MAG  PHASE
   .50       5.3    -10
   .80       5.2    -15
  1.20       5.0    -22
  1.90       4.8    -33
  3.00       4.6    -48
  4.30       4.7    -67
  6.30       5.4    -99
  8.20       6.1   -134
 10.60       5.9   -186
LEAVING PVMOD

STOPPING VEXEC
 29 JUL 76   20.53.42
1
```

9. DETAILS OF PROGRAM OPERATION

In order to make effective use of the PIVIB program, the user should be aware of the following details of the program operation.

9.1 UNITS CONVENTION

The following conventions must be followed regarding units:

1. Frequency is given in radians/sec
2. Angular acceleration is given in radians/sec^2
3. Linear acceleration is given in g's (except for EPR)
4. EPR acceleration is given in inches/sec^2
5. EPR velocity is given in inches/sec
6. EPR displacement is given in inches

9.2 CONSEQUENCES OF OVERLAYING

As was mentioned in Section 2, the PIVIB program is divided into overlays, with the BDMOD module and PVMOD module residing in separate primary overlays. Normally all the data in an overlay is lost when an overlay is read in over it. However, in the PIVIB program virtually all the data (i.e. transfer functions, system dynamics, etc.) in the BDMOD and PVMOD modules is saved on a file at these times, and is restored when the overlays are recalled. The exception to this restoration rule is the VBINT parameters of the PVMOD module. These parameters are lost when control leaves the PVMOD module. This was done to make changes to the remainder of the program unnecessary should the VBINT submodule be revised. Consequently, the VBINT parameters must be respecified each time the PVMOD module is entered.

9.3 NULL TRANSFER FUNCTIONS

As a convenience, when nulling entire groups of transfer functions, the following convention may be employed. If on the BIOTR Option Identifier Card (See Section 7.2.3) NUM1 = 99 and/or NUM2 = 99, then all the output and/or input channels of the designated transfer function will be nulled. Note that the following BIOTR Parameter Card must specify a null transfer function NULL.

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